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The B-1B Bomber and Options for Enhancements

A SPECIAL STUDY

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THE B-1B BOMBER AND OPTIONS FOR ENHANCEMENTS

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PREFACE

The B-1B bomber has many special features that enhance its ability to penetrate Soviet air defenses. Even so, many reported deficiencies--including shortcomings in the bomber's defensive and offensive avionics and a range that is shorter than anticipated--have instilled doubts about its capability to perform the mission for which it was originally designed. These reports have raised three fundamental questions:

- How serious are the deficiencies?
- Should the United States change current plans and use the B-1B as a standoff bomber carrying cruise missiles rather than as a penetrating bomber?
- What enhancements should the Congress fund to improve the B-1B as either a penetrating bomber or as a standoff bomber?

This study by the Congressional Budget Office (CBO), performed at the request of the House Committee on Armed Services, addresses the first two issues and then examines several options for enhancing the B-1B bomber. In keeping with CBO's mandate to provide objective analysis, the study does not recommend any particular course of action.

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August 1988

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SUMMARY

The United States is modernizing each leg of its "triad" of strategic nuclear weapons, which includes land-based intercontinental ballistic missiles, sea-launched missiles, and bombers. Bombers are being modernized in several ways. The United States is developing the new B-2 or "stealth" bomber, which incorporates features that hide it from enemy radar. Older B-52G and B-52H bombers are being modified to carry air-launched cruise missiles--small, pilotless drones that can be launched at long distances from a target. Two new weapons for bombers are also being developed: an advanced cruise missile for long-range attacks and a new short-range attack missile.

In addition to modernizing existing aircraft, the United States has just completed deployment of 100 new B-1B bombers that are the focus of this analysis. Those bombers have experienced a variety of problems that diminish their performance. The Air Force is striving to solve those problems. Moreover, it will probably propose a package of enhancements to expand the B-1B's capabilities. If all enhancements currently under consideration are pursued, that package could cost as much as $8 billion.

This study first reviews the status of the Air Force programs to correct the problems with the B-1B and then reviews the choices the Congress could make regarding the anticipated enhancements. Those choices depend in large part on the mission selected for the B-1B bomber. Should it be employed as long as possible in a role that requires it to penetrate Soviet airspace to attack targets at short ranges? Or should it be transferred to a standoff role, employing cruise missiles to attack targets at longer ranges?

THE B-1B BOMBER

The B-1 bomber was developed as a high-speed aircraft designed to penetrate Soviet airspace, evading Soviet air defense radars by flying low to the ground. The Carter Administration canceled the first ver-

sion of the B-1, now referred to as the B-1A, however, arguing that employing B-52s as standoff bombers would maintain the effectiveness of the air-based leg of the strategic triad at lower cost. The Carter Administration also had begun development of the stealthy B-2 bomber for the role of penetrating enemy airspace.

The Reagan Administration disagreed and resurrected the B-1, partially redesigning the aircraft and naming it the B-1B. Under the Administration's "two-bomber" plan, the B-1B aircraft is intended to serve as a penetrating bomber until the B-2 bomber is deployed in the 1990s. At that time, the B-1B would be used for "shoot-and-penetrate" missions, launching externally carried cruise missiles before penetrating Soviet defenses and attacking targets with bombs and short-range missiles. The first squadron of 15 B-1B bombers became operational in October 1986, and subsequent deliveries were on or ahead of schedule. The one-hundredth B-1B was delivered to the Air Force on April 30, 1988.

The costs of deploying the B-1B have remained relatively close to original estimates. The "baseline" costs of the B-1B bomber will be close to the ceiling of $20.5 billion (in 1981 dollars) established by the Congress. Baseline costs exclude some items that are necessary for deploying the B-1B, including certain physical facilities and flight simulators. B-1B costs in these nonbaseline categories have exceeded the original estimates. Nonetheless, including all costs, the B-1B program will probably be no more than 14 percent above estimates presented by the Administration in 1981.

PROBLEMS THAT LIMIT THE B-1B's PERFORMANCE

Since the B-1B became operational, many problems have surfaced that might diminish its performance as a penetrating bomber. Four of these reported problems are serious, while the others are relatively minor. The Air Force has already solved some of these problems and anticipates finding and carrying out remedies for most of the rest by 1992. But the most serious problem--deficiencies in the defensive avionics system--is not likely to be solved by 1992, leaving in doubt the time when the B-1B will meet all its original design specifications.

Major Problems

The more serious problems involve deficiencies in the B-1B's defensive and offensive avionics; in its payload capacity during low-altitude, terrain-following flights; and in its logistical support.

Shortcomings in Defensive Avionics. Redesign of the defensive avionics to protect the B-1B from Soviet air defenses is the most important and potentially most expensive problem faced by the Air Force. The Air Force had initiated a three-phase plan designed to bring the defensive avionics system on all B-1B bombers up to the design specifications by 1992.

In recent tests of the second phase of that plan, however, the Air Force found that the system's basic architecture--the way the system processes enemy radar signals--is deficient. Although the system can identify and counter the "top 10" airborne threats in a low-threat environment, it would be overwhelmed in a high-threat environment and would be unable to use appropriate electronic countermeasures against Soviet defenses.

The Air Force is now evaluating this problem in detail, and a report is expected in October 1988. It is now unlikely that the Air Force will meet its previous goal of bringing the defensive avionics system on all B-1Bs up to the design specifications by 1992. Also, the cost of reaching those design specifications may rise, potentially causing the baseline costs of the B-1B to exceed the Congressional ceiling of $20.5 billion.

Small Payload Capacity. The B-1B cannot fly at as high an angle of attack (angle between the wing and relative air flow) as anticipated, reducing the bomber's payload (fuel and munitions) during low-altitude, terrain-following flight to about 125,000 pounds, which is significantly less than planned. This smaller payload reduces the amount of fuel the B-1B can carry, limiting its range at low altitudes to about 1,300 miles, which is insufficient for many strategic missions.

To improve the B-1B's payload capacity and therefore its range, the Air Force is modifying the B-1B's basic flight control system to enable the bomber to fly at higher angles of attack. One modification, the Stall Inhibitor System (SIS), will improve the B-1B's payload

capacity by about 30,000 pounds, increasing the low-altitude, terrain-following range of the B-1B to roughly 1,800 miles. The Air Force hopes that a second modification, the Stability Enhancement Function (SEF), will enable the B-1B to carry an additional 80,000 pounds, which could increase the B-1B's terrain-following range to more than 3,000 miles.

The Air Force completed installation of SIS on the first group of B-1Bs (bombers numbered 2 through 18) in June 1988 and is scheduled to complete installation on the remainder by June 1990. Installation of SEF is scheduled for completion by January 1992.

Offensive Avionics: High Rate of Unnecessary Flyups. The automatic terrain-following (ATF) system has caused a high rate of unnecessary "flyups," incidents in which the B-1B pitches up rapidly because it senses obstacles that do not exist or reports suspected malfunctions during a self-check. The Air Force is solving this problem, which wastes fuel and exposes the bomber to enemy air defenses, by revising software that controls the system. Although recent test-flight data indicate that problems remain, revised software should enable the Air Force to reach its goal of an average of 15 minutes between flyups under all types of conditions such as terrain, weather, altitude, speed, and so on.

Shortcomings in Logistical Support. The supply of trained flight crews and the provision of spare parts have been the main logistical challenges. The Air Force is rapidly resolving the first problem; it has reached the goal of one flight crew per primary authorized aircraft and expects to certify all crews in low-altitude flight by November 1988. The provision of spares is more complex. More spare parts are being delivered, but the number of flight hours--and therefore the demand for spare parts--has grown as more planes are delivered and more crews are trained. It is not yet possible to determine whether these factors will increase or decrease the shortage of spare parts in the near term, but the problem will eventually be resolved if spare parts are adequately financed.

Minor Problems

The B-1B has suffered many other minor problems. The Air Force has largely resolved several of these problems including fuel leaks, interference between the offensive and defensive avionics, inadequate performance of the on-board Central Integrated Test System, and problems with the release of weapons from the bomb bays. Also, although some questions have been raised about the ability of the B-1B to carry cruise missiles externally, there does not appear to be a significant problem. Two other reported problems--that the bomber is overweight and unable to fly at required altitudes--are based on misconceptions.

THE STRENGTH OF SOVIET AIR DEFENSES AND THE ROLE OF THE B-1B

A sophisticated weapons system like the B-1B bomber is never really complete. Even as the Air Force seeks to correct problems in the original B-1B design, the service is considering enhancements to improve the bomber's capability. Though not yet formally presented to the Congress, some of these enhancements are likely to be proposed in the Administration's defense budget for fiscal year 1990.

The desirability of many of these enhancements depends on the B-1B's future mission. Should the bomber continue as long as possible to penetrate Soviet air defenses? Or should it move to a standoff role, in which it launches long-range cruise missiles at targets while flying outside Soviet defenses?

These questions require analysis of two issues: How difficult is it to penetrate Soviet air defenses? What are the relative merits of a penetrating bomber compared with those of a standoff bomber?

The Strength of Soviet Air Defenses

Estimates of the B-1B's ability to penetrate Soviet air defenses in a retaliatory strike are affected by many factors, including:

- The circumstances (Did the Soviet attack follow a crisis or come out of the blue?);
- The number of U.S. ballistic missile warheads dedicated to suppressing Soviet air defenses;
- The effect of high-altitude electromagnetic pulse on Soviet military electronics, and the impact of U.S. ballistic missile warheads on the Soviet command system;
- U.S. tactics (such as using air-launched cruise missiles carried by B-52s to suppress defenses and using fighters to attack Soviet aircraft that carry tracking radars) and Soviet tactics (such as the number of fighters dedicated to intercepting U.S. bombers);
- The choice of targets, which may or may not be defended; and
- The effectiveness of particular Soviet defensive systems and of the B-1B's countermeasures.

There are reasonable arguments for selecting different assumptions in regard to these factors. Thus, one could construct scenarios in which the B-1B currently penetrates Soviet air defenses easily and would continue to do so through the 1990s. One could also construct scenarios in which the bomber currently suffers a high rate of attrition and performs even worse as better Soviet defenses are deployed.

The Air Force evaluated the factors noted above in 1981 and concluded that the B-1Bs would, with an acceptable rate of attrition, be able to penetrate heavily defended areas well into the 1990s. This judgment, however, was based on the B-1B's having a defensive avionics system that meets the baseline requirements. If the Air Force is unable to meet those requirements, that judgment might be unjustified.

Merits of Penetrating and Standoff Bombers

Advocates of penetrating and standoff bombers have different perspectives on the relative merits of penetrating and standoff tactics.

Advantages of Penetrating Bombers. Proponents of penetrating bombers claim that such bombers have many potential advantages over bombers that stand off and launch cruise missiles. One advantage, they argue, is that, because a penetrating bomber can carry a larger warhead and deliver it accurately, the bomber is more effective against Soviet targets that are heavily hardened against nuclear attacks--such as silos for intercontinental ballistic missiles (ICBMs) and command centers. A bomber also can conduct a "damage assessment/strike" mission, flying close to a potential target to determine if it was destroyed by a previous warhead and, if it was not, to attack it.

Proponents further contend that the penetrating bomber is the best platform for attacking targets that can move about, such as mobile ICBMs. Bombers have both the sensors for finding mobile targets and the weapons to destroy them; the pilot can use human judgment to select the best targets and tactics.

Moreover, a penetrating bomber can penetrate terminal defenses more effectively than cruise missiles. Whereas cruise missiles approach a target slowly, a bomber launches short-range missiles that approach the target at a high speed and angle, making them much harder to shoot down. It also can deliver conventional munitions to support the United States in conflicts around the world.

Penetrating bombers may also offer advantages in ongoing arms control negotiations. Under counting rules for limiting warheads, which have reportedly been accepted by both the United States and the Soviet Union, the United States could deploy more nuclear warheads if it deploys penetrating bombers than if it deploys standoff bombers. Each bomber carrying bombs and short-range attack missiles would be counted as only one warhead; each bomber carrying cruise missiles would be counted as carrying a higher number of warheads yet to be negotiated.

Advantages of Standoff Bombers. Proponents of standoff bombers challenge many of these arguments for penetrating bombers and note additional advantages for standoff bombers equipped with cruise missiles. They say that the arguments in favor of penetrating bombers are flawed for a number of reasons:

- Penetrating bombers may not be the best weapon for destroying Soviet targets, such as command centers and ICBM silos, that are hardened against nuclear attacks. Ballistic missile warheads, which arrive quickly and minimize the chance these facilities will be used to attack the United States, may be more effective.

- Penetrating bombers may not be the best choice for the damage assessment/strike mission, since flying over a facility might expose the bomber to Soviet air defenses. A better approach would be to target the facility with a second warhead carried by either a ballistic missile or a cruise missile, leaving the bomber free for other tasks.

- The United States does not currently have the sensors necessary to find Soviet mobile missiles. When such sensors become available, a low-flying bomber like the B-1B might not be the preferred platform for the mission since it would have to fly higher to use them, exposing itself to Soviet air defenses.

- Even if they are not designed to penetrate enemy defenses, standoff bombers can be useful in conventional conflicts by using conventional standoff weapons.

- The United States should not agree to an arms control treaty that favors penetrating bombers over cruise missiles if the bombers are not the most cost-effective method of attacking Soviet systems.

Advocates also claim that standoff bombers equipped with cruise missiles have advantages over penetrating bombers. Like penetrating bombers, air-launched cruise missiles exploit weaknesses in Soviet air defenses by flying low. But the missiles have a smaller radar cross section, making it more difficult for Soviet radars to find them.

Moreover, a standoff bomber launching cruise missiles (one B-1B can carry up to 20 cruise missiles) overwhelms air defenses with superior numbers. Cruise missiles also are very flexible. They could be operated as decoys, equipped with defensive avionics, or equipped with sensors for the damage assessment/strike mission or missions against mobile targets.

Standoff bombers may hold down the costs of the U.S. bomber fleet. Pursing only a standoff capability in the future would save money by enabling the United States to cancel both the SRAM II and the B-2 stealth bomber.

As with the issue of the B-1B's ability to penetrate Soviet defenses, this study cannot reach a final conclusion about the desirability of a penetrating bomber compared with a standoff bomber. But there are questions about the merits of both types of bombers that the Congress should consider while assessing which, if any, enhancements to approve for the B-1B.

ENHANCEMENTS FOR THE B-1B BOMBER

The Air Force is considering enhancements that relate to offensive avionics, defensive avionics, command and control, weapons integration, and supporting systems. These enhancements can be split into four functional groups. One group would improve supporting systems that would enhance the B-1B as both a standoff bomber that carries cruise missiles and as a penetrating bomber. The second group would complete preparations for the B-1B to carry cruise missiles on either shoot-and-penetrate missions or standoff missions. The third and fourth groups would enhance the B-1B as a penetrating bomber: the third would improve survivability, and the fourth would improve flexibility.

Of course, the Congress need not approve any enhancements to the B-1B bomber, leaving it with the baseline cost and capability discussed above. But, if history is a guide, enhancements to the capability of a major weapons system will be seriously considered.

Option 1: Improve Basic Support Systems

This option would fund six enhancements that improve systems that support the B-1B as either a standoff or a penetrating bomber. These enhancements would improve the B-1B's navigation and communication capability, further "harden" the aircraft against high-altitude nuclear blasts, redesign some components to increase their reliability, and make other modifications (see the Summary Table).

The costs of this option would be about $1.2 billion over the next five years and $1.7 billion in total. (Costs for this and subsequent options are based on preliminary Air Force estimates.)

The enhancements in this option contribute to the B-1B's capability whether it operates as a penetrating bomber, shoot-and-penetrate bomber, or standoff bomber. Thus, the enhancements are not related to the debate concerning the B-1B's future role and would be consistent with implementing any of the other options discussed below. In addition, several of the enhancements raise little controversy. After acquiring the B-1B, maintaining its resistance to the effects of high-altitude nuclear blasts seems sensible; and given the billions of dollars being spent to deploy the NAVSTAR navigation satellites and MILSTAR communication satellites, it also makes sense to enable the B-1B to use the capabilities they provide.

Option 2: Improve the B-1B's Capability to Carry Cruise Missiles

Since the capability to carry cruise missiles was incorporated into the design of the B-1B, few enhancements are required to enable most B-1Bs to operate as shoot-and-penetrate bombers or standoff bombers. The two enhancements included in this option are described in the Summary Table. Indeed, this is the least expensive option, costing only about $90 million.

Selection of this option probably would not end the B-1B's role as a penetrating bomber. The Air Force still anticipates solving the problems in the B-1B's defensive avionics and has estimated that the B-1B, in its baseline configuration, would be an effective penetrator well into the 1990s and possibly longer. This option would therefore be compatible with the Administration's current "two-bomber" plan, in

which the B-1B would be maintained as a penetrator until the B-2 is deployed. It would also be compatible with an alternative approach in which the United States does not procure the new B-2 penetrating bomber and instead uses the B-1B as a standoff bomber to maintain the effectiveness of the bomber leg of the strategic triad.

This option is also compatible with use of the B-1B in a conventional conflict. The B-1B probably would not be used to fly over well-defended targets and drop conventional munitions, given the high risk that the bomber would be shot down. More likely, it would be equipped with standoff conventional munitions for which the baseline B-1B would be an effective platform.

For proponents of penetrating bombers, however, this option has a major disadvantage: if the B-2 is not deployed, or if its deployment is delayed significantly because of budgetary limits or technical problems, the United States could find itself without an effective penetrating bomber at some future date. In that case, the country would forfeit the advantages of penetrating bombers noted by their proponents.

Option 3: Improve the B-1B's Survivability as a Penetrating Bomber

This option would fund seven improvements designed to enhance the B-1B's capability to penetrate Soviet air defenses by better enabling the bomber to destroy or outwit those defenses. These enhancements include the integration of the new short-range attack missile (SRAM II) and improved electronics for jamming or deceiving enemy radars (see the Summary Table).

The major advantage of this option is that it would extend the period during which the B-1B would be an effective penetrator of Soviet air defenses. This should ensure that the United States would continue to have an effective penetrator until the B-2 is developed and deployed, even if technical problems delay its deployment. Opponents of the B-2 might also favor this option because it may make postponement or cancellation of the B-2 more reasonable. When the enhanced B-1B penetrating bomber becomes susceptible to Soviet air defenses at some future date, the alternatives of procuring a new bomber--the B-2 or some yet-to-be designed aircraft--or of switching to dependence on a standoff bomber could be debated anew.

SUMMARY TABLE. DESCRIPTION AND COST OF ENHANCEMENT PROGRAMS FOR THE B-1B BOMBER
(Costs in millions of current dollars)

Enhancement Program	Description	1990-1994	Cost to Complete	Total Cost
	Option 1: Improve Basic Support Systems			
Second Inertial Navigation System	Provides a second INS to back up the first, which establishes the B-1B's position by measuring its movements from a reference point	30	0	30
Global Positioning System Receivers	Integrates receivers for GPS, a satellite system that enables the B-1B to determine its precise location	50	10	60
MILSTAR Communications Satellite System	Integrates terminals for MILSTAR, a satellite system designed for communication during a nuclear war	170	20	190
Reliability and Maintainability	Redesigns parts to improve their reliability	590	0	590
Hardness Against Nuclear Blast	Tests and designs parts to maintain their resistance to nuclear effects such as electromagnetic pulse	30	0	30
Interface for External Weapons	Installs wiring for carrying advanced munitions on the B-1B's external pylons	300	490	790
Total		1,170	520	1,690
	Option 2: Improve the B-1B's Capability to Carry Cruise Missiles			
Cruise Missile Capability	Equips seven B-1B bombers, which were not equipped during production, to carry cruise missiles	60	0	60
External Observable Differences	Develops and installs EODs, modifications that would distinguish B-1Bs equipped to carry cruise missiles from those that are not so equipped	30	0	30
Total		90	0	90

SOURCE: Compiled by the Congressional Budget Office from data supplied by the U.S. Air Force.

SUMMARY TABLE. Continued

Enhancement Program	Description	1990-1994	Cost to Complete	Total Cost
Option 3: Improve the B-1B's Survivability as a Penetrating Bomber				
Integration of SRAM II	Wires bomb bays for the #1760 weapon interface required for control of the SRAM II short-range attack missile	610	0	610
Monopulse Countermeasure	Improves ability to jam or confuse monopulse radars on Soviet fighters	540	900	1,440
Forward Warning System	Detects air-to-air missiles approaching the bomber from the front	270	390	660
Improved #1122 Countermeasure	Improves this classified system for countering Soviet air-to-air missiles	60	0	60
Research and Development Assets	Purchases parts of defensive avionics system for use in developmental testing at laboratories	170	0	170
Operation of Anechoic Chamber	Operates an anechoic chamber to test the B-1B's defensive avionics system	70	0	70
General Avionics Enhancements	Improves data storage and displays for terrain-following system and assessment of defensive threats	360	0	360
Total		2,080	1,290	3,370
Option 4: Improve the B-1B's Flexibility as a Penetrating Bomber				
Improved Synthetic Aperture Radar	Improves resolution of ground-mapping capability	620	20	640
High-Resolution Infrared Sensor for Targeting	Provides high-resolution infrared images to enhance targeting of mobile missiles	390	620	1,010
On-Board Mission Planning System	Provides computer and data facilities for planning and evaluating changes in the B-1B's basic mission	500	90	590
Low-Resolution Infrared Sensor for Situational Awareness	Provides infrared images of surrounding terrain, enhancing low-altitude or nighttime navigation	370	130	500
Total		1,880	860	2,740

This option would cost substantially more than Options 1 and 2--about $2.1 billion over the next five years, with a total cost of $3.4 billion. Yet it is not clear that this investment is necessary to maintain the B-1B as a penetrating bomber, since the baseline B-1B is expected to be effective in that role--assuming remedies can be found for the shortcomings in its defensive avionics--at least through the mid-1990s. Moreover, in the opinion of proponents of standoff bombers, this option would spend money without achieving any significant capability not currently possessed by standoff bombers equipped with cruise missiles. As noted above, proponents argue that existing bombers equipped with cruise missiles challenge Soviet air defenses better than a penetrating bomber like the B-1B, with or without enhancements.

Option 4: Improve the B-1B's Flexibility as a Penetrating Bomber

This option would fund four modifications that would improve the B-1B's flexibility during a penetrating mission. The enhancements would improve the B-1B's ability to search for mobile targets, to navigate during low-altitude, terrain-following flight, and to plan changes during a mission (see the Summary Table).

Based on preliminary estimates, this option would cost about $1.9 billion over the next five years and $2.7 billion in total. Choosing this option would be consistent with also implementing Option 1 (improve basic support systems) and Option 3 (improve the B-1B's survivability) to maximize the B-1B's capability as a penetrating bomber. The cost for the three options together would be about $5.1 billion over five years and $7.8 billion in total.

By improving sensors and autonomous mission-planning capability, these enhancements might improve the B-1B's ability to find and destroy mobile targets such as mobile Soviet ICBMs. The better sensors might also improve the B-1B's ability to conduct damage assessment/strike missions and, potentially, conventional missions.

From another viewpoint, however, even with the improved sensors, the B-1B falls short of having the capability to find and attack mobile targets effectively. Among other factors, the B-1B would not have the range to search a large area and, in flying higher to try to

search, would expose itself to Soviet air defenses. Moreover, it is not evident that these additional enhancements would significantly improve the B-1B's ability to perform its primary penetrating mission against fixed targets.

CHAPTER I

INTRODUCTION

The United States has several types of strategic nuclear weapons with which it can attack a potential enemy from great distances. The traditional "triad" of strategic weapons comprises sea-based ballistic missiles, land-based ballistic missiles, and long-range bombers.

Many strategic programs are under way that will greatly expand the capability and flexibility of this triad. For the sea-based leg, the United States is procuring the more accurate and powerful Trident II submarine-launched ballistic missiles (SLBMs) for initial deployment on Trident submarines in 1990 and is deploying nuclear sea-launched cruise missiles, which can be launched from either submarines or surface ships. To modernize the land-based leg, the United States is completing deployment of 50 ten-warhead MX intercontinental ballistic missiles (ICBMs) in concrete silos. In addition, the United States is considering the deployment of two mobile ICBM systems. If the programs are funded, a small single-warhead ICBM would be deployed on specially configured trucks, and the ten-warhead MX ICBM would be deployed on railroad cars. Finally, the United States is upgrading the bomber leg of the triad by equipping some B-52 bombers with cruise missiles, fielding the B-1B bomber, developing the B-2 "stealth" bomber, and developing improved weapons--the advanced cruise missile and a new short-range attack missile, the SRAM II.

This study focuses on one element of these modernization programs--enhancements to the newly deployed B-1B bomber.[1] The focus has been chosen to address in detail questions regarding reported deficiencies in the B-1B's capabilities and the issue of whether the B-1B should be employed in the future as a penetrating bomber or as a standoff bomber that carries cruise missiles.

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1. For an overview of basic options for each leg of the strategic triad, see Congressional Budget Office, *Modernizing U.S. Strategic Offensive Forces: Costs, Effects, and Alternatives* (November 1987).

EVOLUTION OF THE STRATEGIC NUCLEAR BOMBER

In the beginning of the nuclear age, the bomber was the sole means of delivering a nuclear weapon to a distant target. On August 6, 1945, the Enola Gay, a U.S. B-29 bomber, dropped a nuclear bomb on the Japanese city of Hiroshima. The United States dropped a second bomb on Nagasaki a few days later.

Bombers continued to be the primary means for delivering nuclear weapons until deployment of intercontinental ballistic missiles began in 1958. Ballistic missiles are rockets that shoot into space and release warheads that fall back to earth to attack their intended targets. These missiles had three basic advantages: they could be based far from the potential battle site, enhancing survivability; the warheads, which approached their targets from space, were immune to existing enemy defenses; and the short time in which the missiles could reach an enemy target (about 30 minutes for ICBMs and less for SLBMs) increased the probability of destroying the enemy's forces before the enemy could use them to respond.

These basic advantages have given ballistic missiles a major role in U.S. strategic forces. Even so, bombers have features that have continued to make them an important part of the triad. Because of their diverse basing and operating characteristics, many technological advances that might enhance the enemy's ability to attack U.S. ICBMs or SLBMs would not enhance the enemy's ability to attack bombers, strengthening confidence in the survivability of nuclear forces as a whole. Furthermore, U.S. officials can enhance the ability of bombers to survive an attack by dispersing them to a greater number of bases, employing higher levels of strip alert (bombers parked on the runway ready to take off), or placing the bombers on airborne alert. The U.S. President can employ this flexibility during a crisis to signal growing concern to a potential adversary. Unlike ballistic missiles, bombers can be recalled, and their slow speed reduces their ability to destroy an enemy's forces in a first strike, potentially enhancing crisis stability.

The main concern about U.S. strategic bombers, however, is that Soviet air defenses--which include anti-aircraft guns, surface-to-air missiles (SAMs), and interceptors (fighter aircraft assigned to attack the bombers) equipped with air-to-air missiles--would become sophis-

ticated enough to shoot them down. This concern has prompted five major developments in the design and tactics of U.S. bombers.

- Because the greater range and accuracy of modern air defense systems have made them very effective against bombers flying at high altitudes, current penetrating bombers have been designed for low-altitude flight. By flying 200 to 400 feet above the ground, a bomber can enhance its survivability by using the curvature of the earth to hide from ground-based radars.

- A penetrating bomber now carries, in addition to bombs, short-range attack missiles (SRAMs) that it can use to attack a target from a distance. This enhances a bomber's survivability when attacking defended targets by eliminating the need to fly over them. The SRAM-A currently carried by U.S. bombers enables them to attack a target from a range of about 40 to 80 miles.

- As an alternative to low-altitude penetration and SRAMs, a bomber can "stand off"--that is, stay outside a nation's air defenses--and fire air-launched cruise missiles (ALCMs). The ALCMs are small, pilotless, jet-powered planes. They fly to their targets using inertial guidance and terrain contour matching, which compares preprogrammed contour map data with measurements of the terrain below to calculate necessary course corrections.

- A bomber can use sophisticated defensive technology to defend itself, including electronic countermeasures, decoys, flares (burning projectiles that draw heat-seeking missiles away from the bomber), and chaff (zinc-coated glass fibers that reflect radar signals, thus confusing radar-guided missiles).

- Many "stealth" technologies are being developed to decrease the amount of radar energy that a bomber reflects, decreasing the range at which an enemy radar can detect it. These technologies, some of which were used on the B-1B, are being applied extensively on the "stealth" bomber currently under development.

ORIGINS OF THE B-1 BOMBER

The first U.S. bomber to incorporate many of these features was the B-52, a large "heavy" bomber built between 1954 and 1962 to replace the B-36. During its service, the B-52 has been equipped with air-to-surface missiles, improved electronic countermeasures, and decoys. The B-52G, for example, was equipped at one time with the Hound Dog air-to-surface missile, which had a range of over 500 miles. It was also equipped with the Quail air decoy, which flew at about the same speed and altitude as the B-52 and created a similar radar image.

Although the B-52 was built as a high-altitude bomber, the Air Force modified many B-52s to serve as low-altitude bombers, maximizing survivability against Soviet air defenses. These modifications included new offensive avionics, updated defensive avionics, and SRAM-A missiles. The SRAMs were intended for destroying targets as well as for destroying air defenses while en route to targets. Also, many B-52 bombers have been modified to carry cruise missiles.

In the 1960s, the Air Force began to consider building a new heavy bomber to replace the B-52. The Air Force produced about 100 supersonic bombers named the B-58, but they proved unsatisfactory and were retired by 1970. The service developed a prototype of the XB-70 in 1964, which was designed to fly three times the speed of sound and operate at 75,000 feet, but canceled it shortly thereafter because of doubts that it would be able to fly high enough to be out of range of Soviet surface-to-air missiles and because it did not compare favorably with the speed and survivability of ICBMs.

The Air Force also procured 76 smaller FB-111 "medium" bombers based on the F-111 airframe. These aircraft are effective penetrators because of their small size, high speed, and ability to fly close to the ground. They have, however, a shorter range and smaller payload than heavy bombers like the B-52. The FB-111's unrefueled range is about 3,000 nautical miles (nm) compared with about 6,000 nm for the B-52 (precise ranges depend on altitude, speed, payload, and weather). The maximum load (including external munitions) for the FB-111 is six nuclear weapons; the B-52G and B-52H can carry 24.

Following development of the XB-70, the search for a new heavy bomber continued under the Advanced Manned Strategic Aircraft

program. That program led to contracts for the development of a new bomber in 1970. The design of the bomber emphasized the capability to fly at low altitudes to minimize exposure to Soviet air defenses. The new bomber would fly lower and faster than the modified low-altitude B-52s and would have a smaller radar cross section.[2] In addition, it would have more advanced offensive avionics for identifying targets and more advanced defensive avionics for outwitting defenses that it could not avoid or destroy.

The new penetrating bomber was named the B-1. Development continued from 1970 through the mid-1970s, but the B-1 was expensive, fueling a debate over whether money was better invested in a new penetrating bomber like the B-1 or in a standoff bomber that would rely on cruise missiles to destroy enemy targets. In June 1977, the Carter Administration canceled the B-1, deciding that a better option was to modify B-52s to carry cruise missiles and continue development of a new bomber incorporating "stealth" technology for avoiding detection by enemy radars.

TWO-BOMBER PROGRAM

Ronald Reagan campaigned for the presidency in 1980 on a platform that included resurrecting the B-1 bomber. The Congress supported this objective indirectly by funding the Long-Range Combat Aircraft program in the fiscal year 1981 Defense Authorization Act. This program was dedicated to deployment of a new bomber by 1987.

As required by this act, the Defense Department studied several options for a new strategic bomber, including the B-1, a stretched version of the FB-111, and the "stealth" bomber started by the Carter Administration. In October 1981, President Reagan recommended developing and procuring not one, but two of these bombers. Under this "two-bomber" program, the Administration would develop a modified B-1 (the modified plane was named the B-1B to distinguish it from the original B-1, now designated the B-1A) as the Long-Range Combat

2. The radar cross section is a measurement of the amount of radar energy reflected by a plane. The smaller a plane's radar cross section, the closer it can fly to enemy radars before being detected.

Aircraft. The Administration also recommended proceeding with development of the "stealth" bomber, which was referred to as the Advanced Technology Bomber and is now designated the B-2.

Under this program, the B-52G would be equipped with cruise missiles. The B-52H would continue as a penetrating bomber until the B-1B was deployed in 1986 to 1988, at which time the B-52H would be equipped with cruise missiles. Then, when the B-2 was deployed as a penetrating bomber some time in the 1990s, the B-1B would be transferred to a "shoot-and-penetrate" role, launching cruise missiles from outside Soviet air defenses and then penetrating with bombs and SRAMs.

The B-1B differed from the B-1A in that it was designed to fly at subsonic rather than supersonic speeds when penetrating Soviet territory and to carry ALCMs as well as bombs and SRAMs. The Air Force determined that supersonic penetration speed and the resulting reduction in time the B-1B would be exposed to enemy radar was not worth the low fuel efficiency incurred at that speed. Also, because the B-1B would be superseded as a penetrator by the B-2 under the two-bomber program, it made sense to include the capability to carry cruise missiles in the initial B-1B design.

In addition, the frontal radar cross section of the B-1B was reduced tenfold over that of the B-1A, primarily by putting baffles in front of the jet air intakes and using more composite materials in constructing the airframe.[3] The schedule for the B-1B called for initial operational capability--defined as the deployment of one operational squadron of 15 planes--by October 1986.

Few details are known about the B-2 bomber because it has remained a "black" program in which the engineering design and planned capabilities are highly classified. The objective, however, is to make it difficult for Soviet radars or infrared sensors to detect the bomber in time to attack it. Techniques to minimize the B-2's radar cross section reportedly include extensive use of composite materials

3. The frontal radar cross section measures the radar energy reflected if the radar is directly in front of the plane. Many analysts contend, however, that the amount of radar energy reflected when the radar is in other positions vis-a-vis the bomber is also important in evaluating a bomber's ability to penetrate. No unclassified estimates are available for the B-1B's radar cross section from these other aspects.

and surface coatings that absorb radar energy, and rounded surfaces that disperse radar energy in many directions.[4]

The Reagan Administration also supported the development of two new weapons for bombers: the advanced cruise missile (ACM) and the SRAM II. The ACM is an air-launched cruise missile that will feature a greater range than the currently deployed ALCM-B and stealth technology to make it less detectable by radar. Initial deployment might be delayed to the early 1990s by production problems. The SRAM II is being developed as a replacement for the currently deployed SRAM-A. It will have greater range, reliability, accuracy, and flexibility. Initial procurement of the SRAM II is scheduled for 1990, with initial deployment in 1993.

STATUS OF THE B-1B PROGRAM

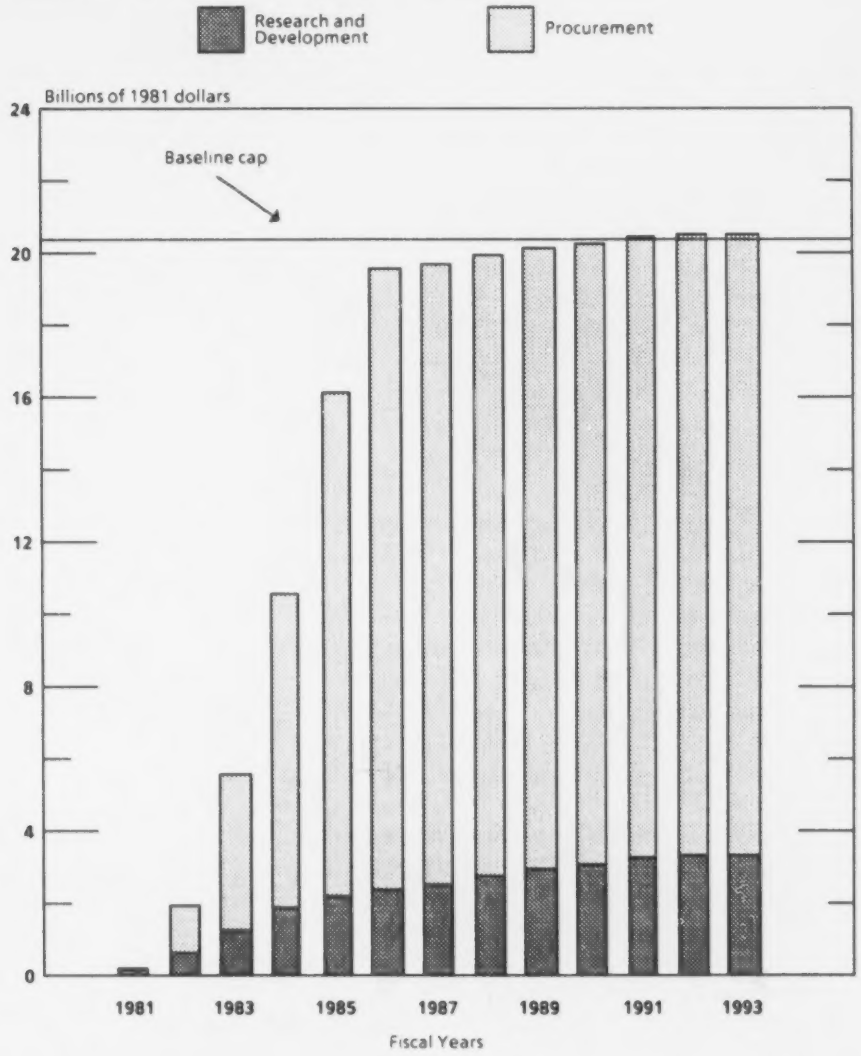
The Congress supported all the basic elements of the two-bomber program outlined by the Reagan Administration in 1981, including the plan to deploy the B-1B by 1986. The Congress demanded, however, a commitment to limiting the basic costs for developing and deploying the B-1B to $20.5 billion (in constant 1981 dollars), which was in addition to several billion dollars that had been spent on developing the B-1 before 1981.

Delivery of the first squadron of B-1B bombers was completed on schedule in October 1986. Subsequent deliveries also occurred on or ahead of schedule, and it now appears that the total cost of the baseline program, as defined by the Air Force, will be close to the cap of $20.5 billion (see Figure 1).[5] However, the price of other "nonbase-

4. For an extensive discussion of stealth technology, see Bill Sweetman, *Stealth Aircraft: Secrets of Future Airpower* (Osceola, Wisc.: Motorbooks International Publishers, 1986).

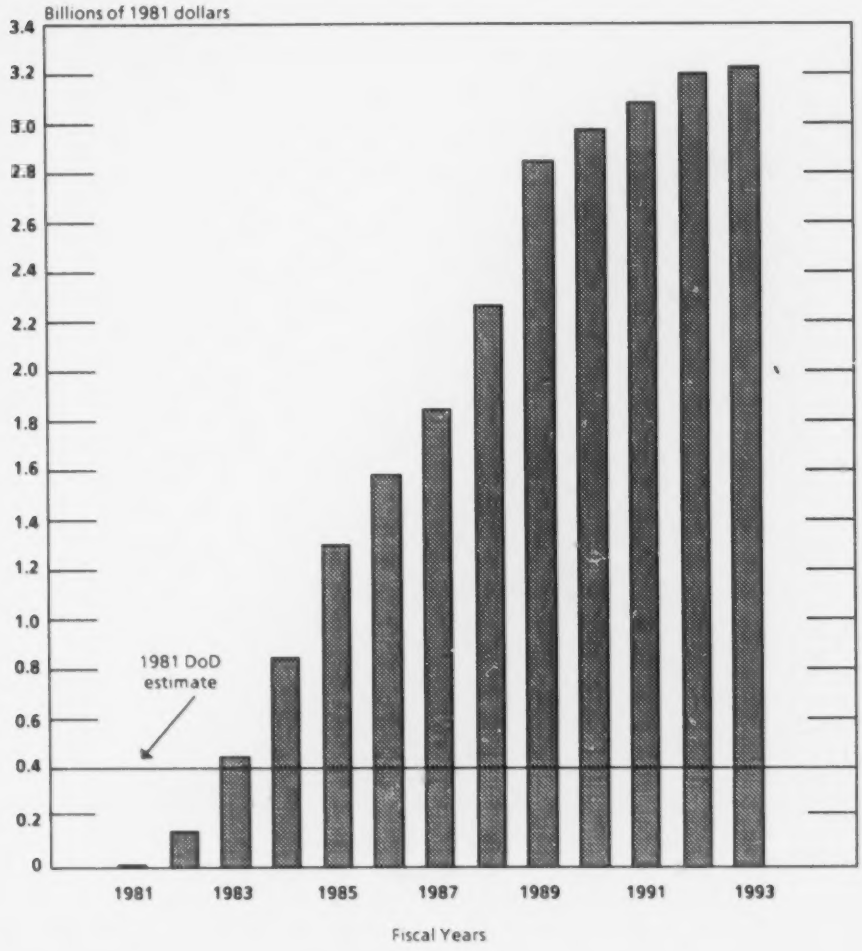
5. Because solutions to several major problems must still be designed, tested, and produced, it is not possible currently to determine whether total baseline costs will be slightly below or above the cost cap. In any event, the significance of the cost cap should not be overstated. Many gray areas exist between the defined baseline and other funding categories pertaining to deployment of the B-1B, including the development of some B-1B components, operation and maintenance of the bomber, enhancements to the bomber, and certain "nonbaseline" costs. The baseline cost cap could be met by shifting some costs into these other categories.

Figure 1.
Cumulative B-1B Baseline Costs, 1981-1993



SOURCE: Congressional Budget Office analysis of data provided by the General Accounting Office. See GAO, *Strategic Bombers: Estimated Costs to Deploy the B-1B* (GAO/NSIAD-88-12, October 1987).

Figure 2.
Cumulative B-1B Nonbaseline Costs, 1981-1993



SOURCE: Congressional Budget Office analysis of data provided by the General Accounting Office. See GAO, *Strategic Bombers: Estimated Costs to Deploy the B-1B*, (GAO/NSIAD-88-12, October 1987). The Department of Defense's 1981 estimate is from *Strategic Force Modernization Programs*, Hearings before the Subcommittee on Strategic and Theater Nuclear Forces of the Senate Committee on Armed Services, 97:1 (1981), p. 110.

line" components of the program necessary for deploying the B-1B bombers has risen. The cost of these nonbaseline components--which include flight simulators, necessary facilities, parts, and support equipment--grew from initial Defense Department estimates of between $300 million and $400 million to about $3.3 billion in 1981 dollars (see Figure 2 on previous page).[6] Overall, therefore, the costs of procuring the B-1B bomber increased about 14 percent following agreement to the cost cap in 1981.

FUTURE ISSUES FOR THE B-1B PROGRAM

Although the B-1B was delivered on schedule and with relatively modest cost increases, its deployment has been controversial because of reports claiming it has a number of problems, such as fuel leaks and inadequate defensive avionics, that reduce its effectiveness as a penetrating bomber. These reports have raised several issues, including:

- How serious are the deficiencies?
- Can they be fixed at a reasonable cost?
- Should the B-1B, as a result of these deficiencies, be employed as a standoff bomber rather than as a penetrating bomber?

While working to fix problems with the existing B-1B, the Air Force is also considering enhancements to the aircraft. The enhancements, which informal estimates suggest could cost as much as $8 billion, have not yet been proposed to the Congress but may well be part of the budget proposal for fiscal year 1990. That raises the issue of whether the Congress should begin to fund enhancements to the B-1B and whether such enhancements should be aimed at performing a penetrating or a standoff mission. This report addresses these issues.

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6. For the Defense Department's original estimates of the costs of nonbaseline components, see *Strategic Force Modernization Programs*, Hearings before the Subcommittee on Strategic and Theater Nuclear Forces of the Senate Committee on Armed Services, 97:1 (1981), p. 110.

   For the current costs of nonbaseline components, see General Accounting Office, *Strategic Bombers: Estimated Costs to Deploy the B-1B* (GAO/NSIAD-88-12, October 1987).

CHAPTER II

WORKING THE "BUGS" OUT

The B-1B has many special features. Its wings sweep back for fast flight close to the ground and sweep forward to increase lift for slower flight or flight at higher altitudes. A small frontal radar cross section enhances its ability to penetrate Soviet air defenses.

In addition, the B-1B has three weapon bays, each of which can carry either eight nuclear bombs, eight nuclear short-range attack missiles, 28 conventional bombs, or a fuel tank. The bulkhead between the front and middle bays can be moved forward, creating a longer bay that can accommodate eight cruise missiles and a shorter bay that can hold a small fuel tank. Each plane can also carry 12 cruise missiles externally.[1]

Despite these special features, deployment of the bomber has been controversial because of reports of deficiencies that diminish its capability. This chapter describes many of those conditions, grouping them into major and minor categories. The chapter also notes the degree to which the problems affect the bomber's performance and reviews the progress the Air Force is making in resolving them.

MAJOR PROBLEMS

Major systems of a bomber include the airframe, the propulsion system, the flight control system, the offensive avionics, and the defensive avionics. On the B-1B bomber, there are no major problems with the airframe or the propulsion system. Several major problems;

1. This is a change from the original plan in which the B-1B would carry 14 cruise missiles externally. Carrying only 12 missiles externally, in addition to eight internally, limits the total number of cruise missiles the B-1B can carry to 20. That is the number of ALCMs that the B-1 was permitted to carry under the SALT II treaty. Also, this change might strengthen U.S. efforts at the START negotiations to credit the B-1B, when carrying cruise missiles, with fewer warheads under a ceiling on strategic warheads.

however, have been reported in other systems. The most important problem is a deficiency in the defensive avionics. Other major problems include a small payload capacity during low-altitude, terrain-following flight; a high rate of unnecessary "flyups" by the automatic terrain-following system; and shortcomings in logistical support for the aircraft.

Deficiencies in the Defensive Avionics System

The B-1B's defensive avionics system has deficiencies that limit its capability to detect and defeat Soviet air defenses. These defenses include perimeter defenses that employ ground-based, surface-to-air missiles (SAMs) and fighter aircraft with air-to-air missiles. In addition, when arriving near a target, a bomber could be attacked by terminal defenses that might include SAMs, air-to-air missiles, and anti-aircraft guns. To penetrate these defenses, bombers follow a three-step strategy: (1) avoid the threat; (2) outwit the threat; (3) destroy the threat.

A bomber's defensive avionics system--electronic hardware and software dedicated to defending the bomber--has a role in each of these steps. One function of the defensive avionics is to locate and identify threats based on their radar emissions. This function alerts the bomber crew so that it can choose whether to avoid a potential threat by changing course or to protect the bomber by pursuing steps two or three of the defensive strategy.

In step two, the crew would use the B1-B's defensive avionics system to attempt to outwit the threat by transmitting signals designed either to jam or to deceive enemy airborne and ground-based radars. In step three, the crew could use a bomber's tail warning function, a radar that searches for missiles approaching the rear of the bomber, to detect such missiles and activate last-ditch electronic countermeasures and physical countermeasures such as the ejection of flares and chaff. Also, the crew could use short-range, air-to-surface missiles to destroy threats such as ground-based radars.[2]

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2. Currently, the air-to-surface missiles carried by bombers on strategic missions are all armed with nuclear warheads. Thus, the crew is unlikely to employ the missiles against targets that are not designated in advance since the nuclear detonation could interfere with the flight plan assigned to other bombers, disrupting a carefully coordinated attack.

Status of the B-1B's Defensive Avionics. Design and production of the B-1B's defensive avionics system, named the ALQ-161, posed one of the most challenging hurdles to deploying the B-1B by 1986. The ALQ-161 required major advances beyond work performed under the B-1A program. In an attempt to complete the system in time for deployment with the first squadron of B-1B bombers, the Air Force developed and produced it concurrently.

This plan failed. Numerous development problems blocked completion of the ALQ-161 system in time for deployment in 1986. As a result, the defensive avionics system installed on each lot of B-1B bombers reflected work to date on an evolving design. By the time B-1B production was completed, many different versions of the defensive avionics system had been produced and deployed, but all fell short of the original specifications. Although the ALQ-161 had some capability to identify the source and location of threats, there were major problems in its active electronic countermeasures and tail warning function.

Consequently, although the bomber can avoid some threats, it is poorly prepared to outwit threats or to destroy attacking missiles. This deficiency will be increasingly important as the Soviet Union deploys more aircraft dedicated to tracking and more fighters equipped with "look-down" radars (see Chapter III).

To remedy this deficiency, the Air Force planned a new engineering program to equip all B-1B bombers by 1992 with a modified ALQ-161 defensive avionics system that meets the original B-1B specifications. This program was organized into three phases labeled Mod 0, Mod 1, and Mod 2.

Mod 0 consisted of modifying the defensive avionics system on each bomber so that the B-1B bombers would have identical systems, facilitating the introduction of Mod 1 and Mod 2. Mod 1 would then modify the ALQ-161 to provide several features including selected automatic (versus manual) jamming and operation of the tail warning function. Mod 1 involved some hardware changes, but this phase focused on developing a new version of the defensive avionics software titled "block 4.0." Additional software and hardware changes would then be made in Mod 2 to bring the ALQ-161 up to the original B-1B

specifications. Installation of Mod 2 was to start in 1989 and be completed on all B-1Bs by 1992.

Installation of Mod 0 was completed on most B-1Bs in 1987. The Air Force chose not to install Mod 0 on 18 B-1Bs to save costs, planning to go directly to Mod 2 when it became available.

The Air Force proceeded to flight-test Mod 1 in March through June 1988. The tests revealed that the defensive avionics had good capabilities to identify and counter the "top 10" airborne threats--that is, the airborne threats thought to present the greatest challenge to the B-1B's survival on a strategic mission.

The tests also demonstrated, however, that Mod 1 cannot process a large number of radar signals simultaneously as required in the B-1B specifications. Thus, the defensive avionics could be overwhelmed in a a high-threat environment, preventing the B-1B from using appropriate electronic countermeasures against Soviet air defenses. The Air Force has concluded that this serious deficiency is caused by the ALQ-161's basic architecture--the way it processes signals on the eight radar bands it covers.

A New Air Force Plan. The Air Force is therefore now rethinking its plan for the B-1B's defensive avionics and has reached three basic conclusions. First, the software version 4.0 developed under Mod 1 can make a limited improvement in the performance of the ALQ-161 and therefore should be deployed on the B-1B bombers.

Second, the Air Force has concluded that software modifications alone cannot overcome the serious deficiency in the ALQ-161's architecture. The Air Force has put Mod 2 on hold and has assigned its Systems Command and Strategic Air Command to study alternative architectures and to present options by October 1988. By changing the architecture so that the ALQ-161 would process signals in only a few radar bands, for example, the Air Force might be able to salvage the capability of the current defensive avionics against the most important air defense threats while keeping the system from being overloaded in a high-threat environment. Also, since Mod 2 is on hold, the B-1B Program Office is preparing a plan to install Mod 0 on the 18 aircraft previously exempted.

Third, the Air Force must begin to consider long-term options for improving the B-1B's defensive avionics, since even the revised ALQ-161 might not meet all the original B-1B specifications--which were based on the air defense threats of the 1980s--let alone the threats of the 1990s. Long-term options might include adding various enhancements already under study (see Chapter IV).

The recent conclusion that the architecture of the ALQ-161 has a serious deficiency leaves in doubt the schedule, cost, and performance of improvements in the B-1B's defensive avionics, at least until the Air Force completes its current review. The B-1B's defensive avionics will probably not achieve the level of performance called for in original specifications for the baseline B-1B bomber in the near term, and may never achieve that level without major modification.

Small Payload Capacity During Terrain-following Flight

The B-1B is designed to fly at low elevations of 200 to 400 feet during a penetrating mission in order to avoid Soviet air defenses. During such terrain-following flights, the B-1B must have the ability to maneuver, including the ability to pull up sharply to avoid hitting hills. To maintain the ability to pull up at the level desired by the Air Force (2.4 g's, or gravitational equivalents, for 10 seconds), however, the B-1B can only carry about 125,000 pounds of munitions and fuel, which is significantly less than originally planned. This situation has occurred because the B-1B cannot, with its basic flight control system, fly at as high an angle of attack (the angle between the wing and the relative air flow) as anticipated, reducing the amount of weight it can carry.

For any given load of munitions, this reduced payload capacity restricts the amount of fuel the B-1B can carry, which in turn limits its range. With a load of eight SRAM-As and eight B61 bombs, for example, the B-1B has a low-altitude, terrain-following range of just over 1,300 miles (see Appendix A for the methodology used in calculating payload capacity and range).[3]

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3. The Air Force has determined that the B-1B meets its specifications for a low-altitude, terrain-following flight of 1,726 miles (1,500 nautical miles). The B-1B can meet this specification, however, only if the bomber's low-altitude flight is straight and level so that the bomber does not need to maneuver. Under these assumptions, the bomber can fly at a heavier weight and increase its range by carrying more fuel.

This low-altitude, terrain-following range is insufficient for many penetrating missions. For example, during a mission in which a B-1B starts flying at a low altitude 300 miles from the coast of the Soviet Union (to escape radar detection), enters the Soviet Union near Murmansk (the northwestern corner of the Soviet Union), attacks targets near Moscow, and continues flying at a low altitude until it reaches the border of the Soviet Union en route to a recovery base in Italy, the B-1B's low-altitude flight would be about 2,000 miles.

Several tactical measures can be taken to extend the B-1B's range, but all have potential drawbacks related to weapon payload, safety, or exposure to Soviet air defenses. One method would be to have the B-1B carry fewer weapons and more fuel. By carrying only four SRAM-As, for example, rather than eight SRAM-As and eight bombs, the B-1B could carry enough extra fuel to fly roughly 300 miles farther. Another method would be to have the B-1B begin its terrain-following flight when closer to the intended target, but this would increase the risk of being detected and attacked by Soviet air defenses. Alternatively, the B-1B could save fuel by flying more slowly during part of its low-altitude mission, but doing so would expose the bomber to air defenses for a longer period, increasing its vulnerability. The B-1B could also fly at a higher weight and accept a reduced ability to maneuver. But this would increase the risk that, being unable to pull up fast enough, the bomber would hit a hill.

A better solution would be to improve the B-1B's flight control system (FCS). The design of the B-1B's basic FCS, which enables the pilot to direct the plane by moving a "stick," determines the maximum angle of attack (AOA) at which the bomber can fly (see Box 1). An improved FCS would enable the bomber to fly at a higher AOA and thus carry more weight. The Air Force is therefore adding two components to improve the B-1B's flight control system: the Stall Inhibitor System and the Stability Enhancement Function.

Stall Inhibitor System. The Stall Inhibitor System (SIS) modifies the B-1B's basic flight control system, which is a hybrid mechanical and "fly-by-wire" system. The mechanical portion of the FCS is similar to the brake system on an automobile: rods connect the pilot's stick to a hydraulic system that in turn moves the flight control surfaces. The fly-by-wire portion, so called because wires carrying electrical signals

BOX 1
Relationship Between Angle of Attack and Lift

The angle of attack (AOA) is a measurement of how steeply a plane is flying. Specifically, it is the angle between the chord of a plane's wing and relative air flow. At low angles, drag is low and therefore less energy is required to propel the plane. But lift (the upward force that opposes the pull of gravity) is also lower, which decreases the load that a plane can carry. At high angles of attack, lift is higher and the plane can carry more fuel or cargo. Drag is also higher, however, and fuel efficiency declines.

This general relationship between AOA and lift is true only over a limited range. At some point, a higher AOA no longer results in greater lift because the high angle of the wing to the air flow creates turbulence, disrupting the required smooth flow of air over the wing and causing an aerodynamic stall. On most planes, this point determines the maximum AOA at which the plane can fly. An advantage of this condition is that the turbulence indicates to the pilot that the plane is approaching its maximum AOA.

On the B-1B and some other planes, however, an aerodynamic stall is not the factor limiting the angle of attack. Indeed, before the B-1B can use the greater lifting capability available at higher angles of attack, the plane is potentially unstable. As the AOA increases, the plane shifts from positive static stability (the center of gravity is in front of the center of lift) where the flight control system (FCS) can easily control the plane's pitch, to neutral or negative static stability (the center of gravity is even with or behind the center of lift) where it is difficult for the FCS to control pitch.

In this situation, where the plane's maximum angle of attack is determined by potential instability rather than by aerodynamic stall, there is no buffeting to warn the pilot that the plane is close to exceeding the maximum AOA. Thus, the B-1B employs mechanical signals--a light and a siren--to warn the pilot.

Determining the maximum AOA in this situation requires subjective evaluation of the flight control system's ability to maintain control of the plane. The Air Force has determined that, in order to allow an adequate margin of safety, the B-1B's basic FCS can operate the plane at 80 percent of the "limit" AOA (defined as the AOA that corresponds to neutral static stability); the FCS triggers the warning light and siren at that point. With the Stall Inhibitor System (SIS), however, the Air Force anticipates that the bomber could operate at 95 percent of the "limit" AOA and thus the light and siren will be triggered at that level. With the Stability Enhancement Function (SEF), the plane may be able to fly at even higher angles of attack. By increasing the operational limits on the angle of attack, SIS and SEF will enable the B-1B to use some of its previously unexploited lift capability.

replace mechanical links, employs a computer called the Stability Control Augmentation System (SCAS). The SCAS interprets the pilot's instructions (based on pressure on the stick) and augments the mechanical system to achieve the desired angle of attack.

The Stall Inhibitor System is essentially a computer that modifies the fly-by-wire side of the basic FCS. It compares the actual AOA with the maximum, or "limit," AOA for current flight conditions. As the actual AOA approaches the limit AOA, SIS cancels part of the signal forwarded to SCAS, thereby forcing the pilot to pull much harder on the stick to fly the bomber at higher angles of attack where it might go out of control.

With this system, the Air Force anticipates that the bomber will have greater maneuverability, flying at 95 percent--compared with 80 percent with the basic FCS--of the limit angle of attack. The Air Force estimates that this improvement would enable the B-1B to carry about 30,000 more pounds of fuel or weapons during high-speed, terrain-following flight. Using this increase for fuel would extend the terrain-following range of the B-1B by roughly 500 miles.

In addition to increasing the B-1B's payload capacity at low altitudes, the ability to fly at higher angles of attack increases the bomber's maneuvering capability when taking off and landing. Flying at a higher angle of attack also enables a bomber to refuel at a higher altitude, improving fuel efficiency and making it less likely that the bomber and tanker will have to refuel while flying through clouds, precipitation, and turbulent air.

The testing and installation of SIS is proceeding in two parts. The first 18 B-1B aircraft were built without any SIS hardware. The testing of SIS hardware--termed SIS1--for those aircraft was completed in March 1988. According to the Air Force B-1B Program Office, the system is working well and no major problems have been encountered. Installation of SIS1 was completed in June 1988. On the other 82 aircraft, the installation of SIS--termed SIS2--began in March 1988 and is scheduled for completion in June 1990. Although SIS2 produces the same performance parameters as SIS1, SIS2 uses the same hardware as the Stability Enhancement Function, discussed below.

The Stability Enhancement Function. The Stability Enhancement Function (SEF) operates much like SIS but it uses additional sensors and refined software to evaluate more clearly the conditions under which the bomber can be safely flown. SEF is designed to permit the pilot to fly the B-1B at high angles of attack--potentially in excess of the limit AOA--when it is safe to do so. The Air Force estimates that the B-1B with SEF will be able to carry up to 110,000 more pounds of fuel or munitions during high-speed, terrain-following flight than if it were equipped only with the basic flight control system. Whereas the Air Force's estimate for SIS is based on substantial testing, however, the estimate for SEF is based on preliminary engineering evaluations and could change substantially.

If the anticipated increase in payload with SEF is used to carry fuel, the terrain-following range of the B-1B could increase, compared with current capability, by about 1,700 miles. Figure 3 compares the range of the B-1B equipped with the basic flight control system, with SIS, and with SEF.

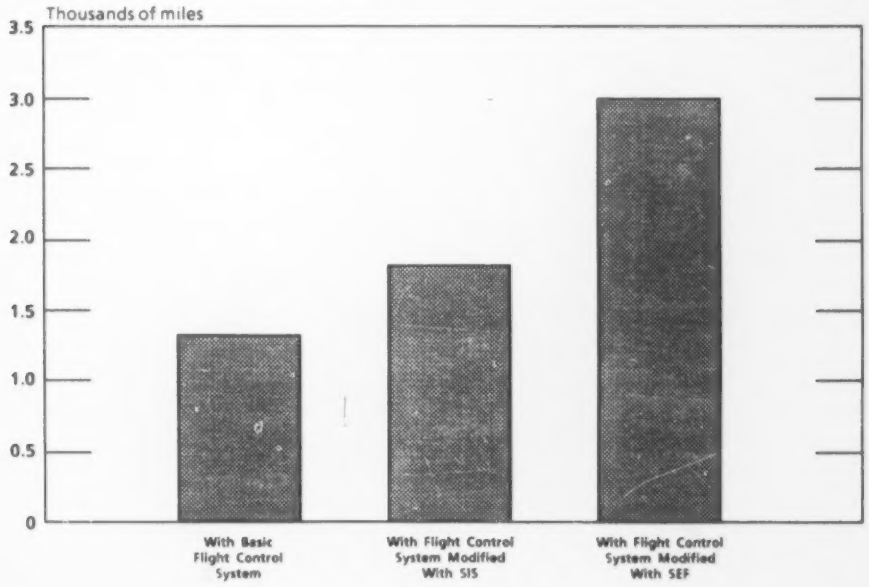
The testing of SEF began in March 1988 and is scheduled for completion in February 1989. The retrofit of SEF is scheduled to occur in two parts. The B-1Bs with SIS1 are to be retrofitted between November 1988 and January 1992. The other B-1Bs are receiving SEF simultaneously with SIS2, between March 1988 and June 1990.

Offensive Avionics: A High Rate of Unnecessary Flyups

Offensive avionics comprise electronic hardware and computer software designed to guide a plane and its weapons to the target. Major elements of the offensive avionics suite on the B-1B bomber are an inertial navigation system (gives current location), a radar altimeter (measures height above the ground), a Doppler navigation radar (measures velocity), and the offensive radar system. The offensive radar system can operate in many different mapping and navigation modes, but the two most important are high-resolution ground mapping and terrain following. The former mode provides maps that help identify targets and feed targeting data to weapons systems. The terrain-following mode makes a profile of the terrain directly ahead of the bomber so that it can fly close to the ground without crashing.

The terrain-following mode is used in the automatic terrain-following (ATF) system, which is essential for low-altitude penetration (see Box 2). The ATF system on the B-1B, however, has suffered from a high rate of unnecessary flyups: the ATF instructs the aircraft to pitch up fast even though there is no obstacle. These unnecessary flyups have been caused by the ATF's detection of nonexistent hills and by "invalid" signals in which the system checks itself and concludes that it is not working satisfactorily. Flyups are a major problem because they expose the aircraft to detection by ground-based radars, waste fuel, and reduce the crew's confidence in the ATF system.

Figure 3.
Approximate Range of B-1B Bomber During Terrain-following Flight at Low Altitudes



SOURCE: Congressional Budget Office analysis of data provided by the Air Force. See Appendix A for discussion of the methodology employed.

NOTE: SIS = Stall Inhibitor System; SEF = Stability Enhancement Function.

BOX 2
Automatic Terrain-following System

The automatic terrain-following (ATF) system is essential for flying close (200 to 400 feet) to the ground. Such flying is difficult when relying on vision alone under the best of conditions (calm, clear weather) and is nearly impossible under more adverse conditions. In addition, a strategic nuclear mission might be conducted at night, and the cockpit windows might be covered by thermal curtains to protect the crew from the flash from a nuclear explosion, making it impossible to fly by vision alone. Finally, flying by vision alone would require such concentration that the pilot would have little opportunity to monitor other important activities. During high-speed, low-altitude penetration, a pilot would be flying only 200 to 400 feet off the ground while traveling more than 900 feet per second. Just one second of inattention or confusion could result in a crash.

The ATF system operates by scanning the terrain ahead with a radar beam and building a profile of that terrain in its memory. If the terrain is flat, these scans can occur many seconds apart, giving the offensive radar system time to devote to other functions such as making high-resolution ground maps. If the terrain is hilly or mountainous, the ATF must scan more often.

The ATF has several safeguards to ensure that the bomber does not crash as a result of a failure in the ATF system. First, if the altimeter indicates that the bomber has moved out of a predetermined tolerance band around the desired elevation, the ATF will trigger an automatic flyup, in which the bomber accelerates rapidly upward to avoid a potential crash.

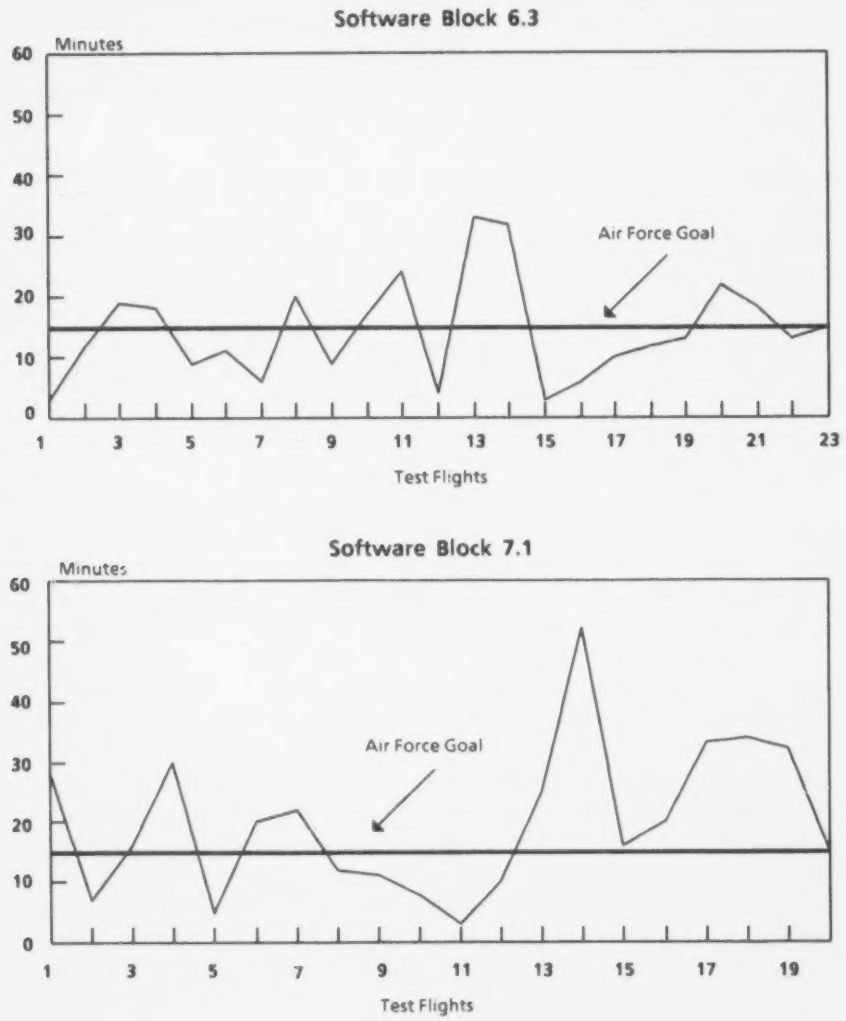
Second, the ATF checks its own performance about 16 times per second. At the end of each check or "frame," the ATF computer sends a "valid" signal to the flight control system if it is working correctly and an "invalid" signal if it is not. More than 500 conditions would cause an invalid signal to be registered. If such a signal is registered several times in a row, the ATF system triggers an automatic flyup.

Another disconcerting but less significant problem occurs when the ATF system directs the plane to pitch down as the bomber approaches a large obstacle. This problem, according to the B-1B Program Office, occurs when the bomber is turning. The ATF system on one scan detects a small hill and instructs the plane to pitch down as the plane passes over it. As the plane begins to pitch down, however, it confronts a larger obstacle that was not in the direct line-of-sight on the previous scan and was therefore undetected. The Air Force believes that the solution is to change the software to limit the rate and magnitude of pitch-downs, smoothing the transition from one scan to the next. The pitch-down problem is being addressed in software scheduled to be flight-tested and delivered to the Strategic Air Command by September 1988.

The Air Force maintains that the excessive flyups, like the disconcerting pitch-downs, can be solved largely by fine-tuning software. Three types of software are involved: the automatic flight software that controls basic aircraft navigation; software that computes the desired flight path; and offensive radar software that controls the radar that maps the terrain ahead of the aircraft. The Air Force is developing, testing, and periodically deploying improved versions of these software packages with the goal of raising the mean time between unnecessary flyups to 15 minutes over all types of terrain.

Between June 1987 and February 1988, the Air Force worked on improving the offensive radar software, testing versions known as block 6.3 and block 7.1. The Air Force data on these tests are not sufficient to demonstrate that substantial progress has been made in resolving the problem of unnecessary flyups. The data show that the mean time between unnecessary flyups on test flights has varied widely, between 3 minutes and more than 50 minutes (see Figure 4). In addition, the data do not paint a clear picture of performance of the ATF system, because they neither provide the length of test flights nor distinguish between test flights conducted under widely varying conditions. Conditions that could influence the performance of the ATF system include weather, the type of terrain covered, the altitude at which the test was conducted, and whether the system was set for a "hard ride" (the bomber follows the terrain more precisely, necessitating more rapid changes in elevation) or a "soft" ride. Finally, the per-

Figure 4.
Mean Time Between Flyups During Test Flights Using Software Blocks 6.3 and 7.1, June 1987 to February 1988



SOURCE: Compiled by Congressional Budget Office using Air Force data.

formance of the ATF system on carefully regulated test flights might not be representative of its performance on deployed aircraft.

The Air Force, while acknowledging that recent data do not provide any identifiable trends, notes that many necessary corrections have been deferred to version 4.5 of the automatic flight software and version 8.1 of the offensive radar software and that, when these versions are fielded, substantial improvement should be made.

In summary, it appears that additional work must be done before the ATF system on deployed aircraft will meet the Air Force performance goal. If the B-1B Program Office is correct in believing that there is no fundamental problem in the ATF hardware, however, work on the software should continue to yield improved performance, eventually meeting the Air Force objectives.

Shortcomings in Logistical Support

A weapons system must be maintained and supported to operate effectively. Logistical requirements include facilities for servicing the aircraft, trained maintenance personnel and flight crews, and adequate supplies of spare parts. To date, the major logistical problems have been insufficient training of crews and lack of spare parts.

Insufficient Training at Low Altitudes. While the Air Force has almost as many crews as desired for the B-1B bombers, those crews have not received an adequate amount of training in flying the B-1B at low altitudes.

Regarding the number of crews, the Air Force has come close to meeting its desired crew ratio (qualified B-1B crews to primary authorized aircraft) of 1.0 during B-1B deployment. As of February 24, 1988, for example, the Air Force had 80 crews for 83 aircraft, with five additional crews nearing graduation. The Air Force also expects to meet its future goals for crew ratios of 1.1 between July 1988 and April 1991 and 1.3 by December 1993.

Many B-1B crews, however, have not had the desired level of training in low-altitude flight, which is essential for accomplishing the B-1B's penetrating mission. This shortcoming is partially the re-

sult of fewer aircraft being available than was planned--either because they have been in the shop being modified or have been grounded by shortages in spare parts. In addition, low-altitude training was interrupted following the crash of a B-1B during a low-altitude training flight in September 1987. The Air Force therefore established a training schedule to recertify flight crews that were certified before the September crash as well as to certify new crews. As of July 1988, 95 percent of the crews that were certified before the crash had been recertified, and 5 percent of the new crews had been certified. The Air Force anticipates that the remaining crews will be certified by November 1988.

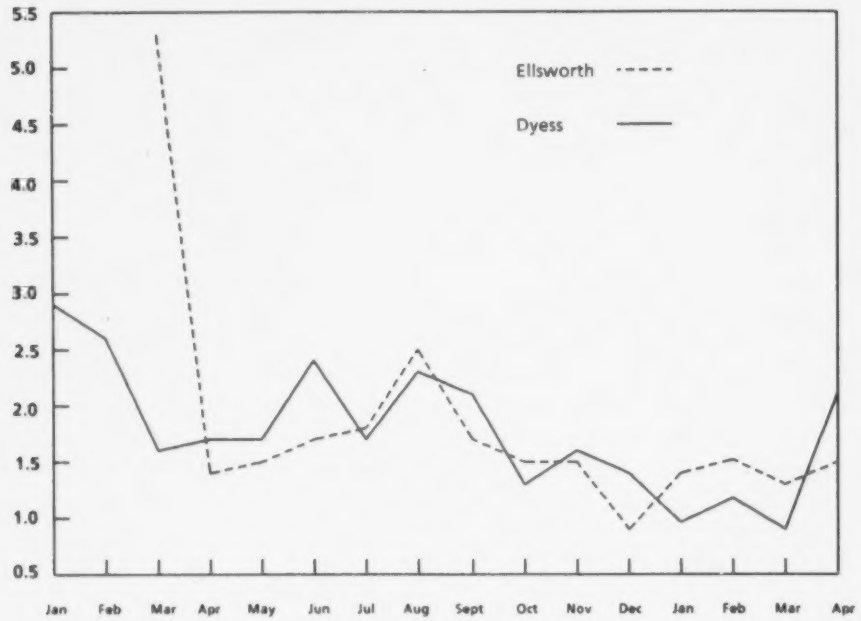
Insufficient Spare Parts. Virtually every sophisticated weapons system suffers from an inadequate supply of spare parts in the first few years of deployment. Supplying parts for aircraft in production takes priority over supplying parts for the inventory of spares. In addition, until the aircraft has been flown, the rate at which various parts will fail can only be roughly predicted. Changes in design among production aircraft complicate the fielding of spares, and budgetary pressures during production encourage the postponement of funding for the procurement of spares.

The B-1B bomber has been no exception to the problem of inadequate spares. Shortages have adversely affected the availability of aircraft both for training and, if necessary, for strategic missions.

The Air Force uses several measures to track shortages of parts including "canns" and "MICAPs." The picture painted by these measures is mixed. The number of "canns"--parts taken from some aircraft to keep other aircraft operating ("canns" is short for "cannibalizations")--per B-1B sortie have oscillated between 0.9 per sortie and 2.2 per sortie between November 1987 and April 1988 (see Figure 5). As the supply of parts improves, a consistent decrease in the number of canns should be evident. The number of "MICAPs"--parts on back order that are considered necessary for performing a mission ("MICAP" stands for "mission incapable part")--has decreased from a total of 935 in September 1987 to 478 in February 1988.

Other measures provide an indication of the impact of spares shortages and modification programs on operations. One measure is

Figure 5.
B-1B Logistical Support as Measured by "Canns" per Sortie at Two Air Force Bases, January 1987 to April 1988



SOURCE: Compiled by Congressional Budget Office using Air Force data.

NOTE: "Canns," short for "cannibalizations," are parts taken from some aircraft to keep other aircraft operating.

the percentage of planned training sorties that the Air Force was able to fly. This measure has increased to 90 percent for the period from October 1987 to January 1988. A second measure is the percentage of deployed aircraft that are fully or partially mission capable. At Dyess Air Force Base, this measure has been as follows:[4]

4. B-1B Operational Test and Evaluation Quarterly Status Reports by the Air Force Operational Test and Evaluation Center (September 1987, January 1988, April 1988, and July 1988).

June-August, 1987	36.2 percent
September-December, 1987	28.2 percent
January-March, 1988	45.9 percent
April-June, 1988	34.1 percent

The eventual goal for this measure is 60 percent to 70 percent.

The Air Force has maintained that the shortages of spare parts will improve substantially in the months ahead, noting that the number of delivered parts is increasing and that the industrial capacity that sustained the B-1B production line can now be diverted to fill the spares pipeline. On the other hand, the greater number of sorties now being flown by the fully deployed B-1B fleet is generating a higher demand for parts.

Too many assumptions are involved for the Congressional Budget Office to forecast the outcome of this struggle between supply and demand on the availability of parts during the next year. But the shortage will probably be alleviated over the next several years if the budget for spare parts is adequately funded.

MINOR PROBLEMS

Many other issues have been raised about the B-1B, including interference between the offensive and defensive avionics, the number of fuel leaks, the performance of the on-board Central Integrated Test System, the weight of the aircraft, the capability of the anti-icing system, inadequate preparation for conventional missions, and problems with carrying and launching various weapons. In addition, the crash of a B-1B bomber after hitting a large bird has raised the issue of whether the B-1B needed modifications to decrease its vulnerability to birds. These issues are addressed briefly below.

Integration of Offensive and Defensive Avionics

One challenge in building a sophisticated bomber is integrating the offensive avionics system, which guides the bomber and weapons to the target, with the defensive avionics system, which watches for

hostile defenses and helps outwit them. The problem is that radar transmissions from the offensive avionics can "leak" into receiving antennas serving the defensive avionics or vice versa.

The B-1B Program Office reports that tests of the B-1B show that the leakage from the offensive and defensive transmitters into the defensive and offensive receivers has not been at levels high enough to cause identifiable problems. To ensure that no problems occur, however, the B-1B has a Radio Frequency Signal Management System to coordinate the offensive and defensive systems. That system has experienced several difficulties, but it appears that they have either been solved or are being addressed (see Box 3). The Air Force, having growing confidence in the compatibility of offensive and defensive systems, has begun to lift restrictions that had been placed on operating them simultaneously during training flights.

Nevertheless, as long as the Air Force continues to modify the B-1B's offensive and defensive avionics, it must keep testing for potential problems of compatibility to make sure that such problems do not go undetected and either cause a crash or disrupt operation of the bomber's defensive avionics.

Fuel Leaks

Fuel in the B-1B is stored in cells within the airframe of the aircraft, including the wings. To save weight, no special lining or fuel bladder is used. The absence of a lining creates a challenge: nearly 300,000 fasteners penetrate the surfaces of the fuel cells, and each fastener must be effectively sealed to avoid a leak. This sealing procedure was not rigorous enough in the first group of B-1Bs, leading to extensive "weeping and seeping" of fuel from various cells. In some cases, such leaks were simply an annoyance and could temporarily be dealt with by not using a particular cell. In others, the leaks grounded the B-1B.

To solve this problem, the Air Force focused much more attention on the sealing process, establishing repair teams and a better system for training technicians, tracking leaks, and inspecting the work performed. These efforts have yielded improvements. Although the

BOX 3

Radio Frequency Signal Management System

The B-1B has a Radio Frequency Signal Management System (RFSMS) embedded in the offensive and defensive avionics systems to prevent them from jamming or confusing each other.

To prevent the defensive system from attempting to classify radar emissions from the offensive system as a defensive threat, the offensive system notifies the defensive system of the frequencies it is using so that the defensive system can ignore them. To prevent the defensive transmissions designed to jam enemy radars from interfering with offensive avionics, the defensive system sends an "avoid" command to the offensive system, instructing it not to employ the band the defensive system is using. When no longer transmitting on that band, the defensive system should send a "delete" command instructing the offensive system to resume employing that band when it is needed.

The RFSMS has experienced at least two problems. First, the offensive system was not keeping track of the "avoid" frequencies correctly, causing it to transmit at times on the banned frequencies. Second, the defensive system would send the "avoid" commands but would fail to send the subsequent "delete" commands, progressively decreasing the number of frequencies the offensive system could use.

According to the B-1B Program Office, the first problem, which required modifications to the Boeing software for the offensive multimode radar, has been solved; improved software has been installed in the deployed B-1Bs. A solution has been identified for the second problem and was to be installed with Mod 1 of the defensive avionics system. This plan might be altered, however, by the current Air Force reevaluation of plans for improving the B-1B's defensive avionics. According to the B-1B Program Office, although the second problem still exists, the operational implications are modest; before the offensive system fails as a result of receiving too many "avoid" signals, the offensive software will opt to ignore them.

average time between leaks each month varies widely as a result of changes of weather, the amount of flying (temperature-induced expansions and contractions as well as flexing during flight cause leaks), and possibly changes in the way leaks are evaluated and reported, the leaks no longer seriously diminish the readiness of the B-1B fleet.

At Dyess Air Force Base, for example, the average flight time between fuel leaks has risen from about five hours to between 15 hours and 70 hours (see Figure 6). Since the first group of B-1B aircraft were deployed at Dyess, this primarily reflects efforts to fix deployed aircraft. At Ellsworth Air Force Base the average flight time between fuel leaks has risen from about five hours to an average of more than 40 hours (see Figure 6). The performance of aircraft at Ellsworth primarily reflects improved workmanship done at the factory before the B-1Bs were deployed. Therefore, although the Air Force is still short of its goal of an average of 130 hours of flight between each fuel leak, significant progress has been made.

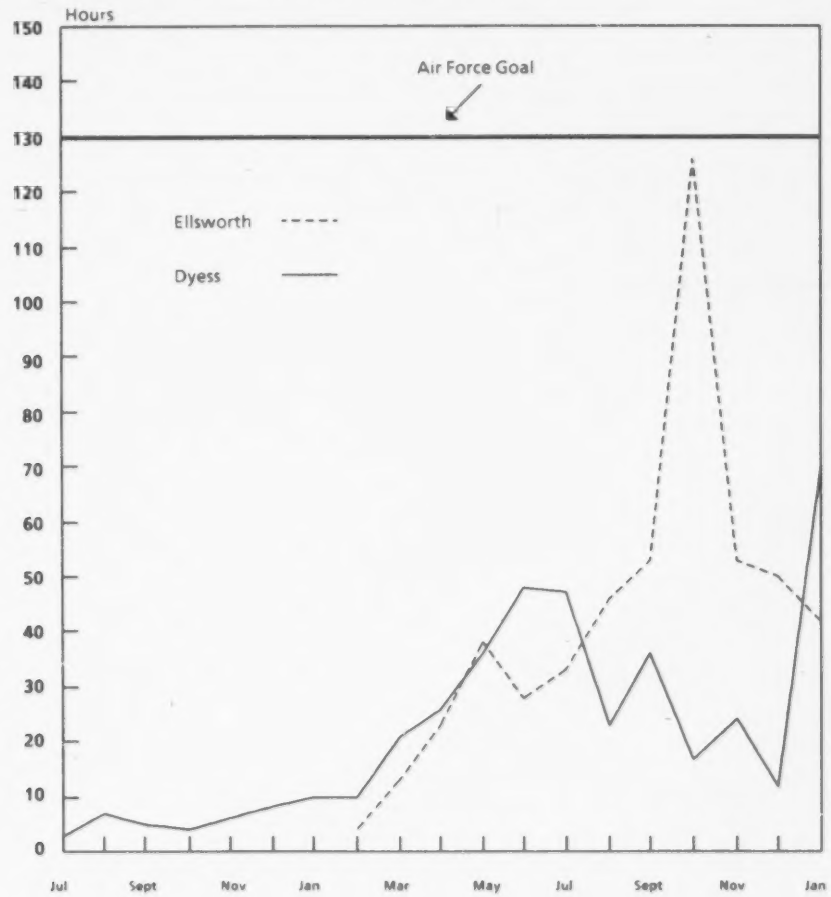
Problems with the Central Integrated Test System

To help technicians on the ground maintain the B-1B, the bomber has a Central Integrated Test System (CITS). This system monitors 22,000 parameters in the airframe, the offensive avionics, and the defensive avionics and then issues any of more than 10,000 different maintenance codes to identify problems. During testing of the B-1B, however, CITS issued as many as 350 false alarms (incorrect identification of a problem) per sortie. This high rate of false alarms greatly diminished the usefulness of the system as an aid to maintenance technicians.

The system's high rate of false alarms was caused partly by faulty hardware but mostly by faulty software. The Air Force addressed the hardware problems, such as sensors that failed to operate correctly, by replacing the faulty equipment. The Air Force also has steadily improved the software.

As a result, the portions of CITS that monitor the airframe and the offensive avionics are now performing well. In tests, false alarms regarding the airframe have dropped from an average of 120 per flight to an average of 20. Flight tests also indicate that the most recent

Figure 6.
Average Flight Time Between Fuel Leaks at Two Air Force Bases, July 1986 to January 1988



SOURCE: U.S. Air Force.

software version will have an average of about nine false alarms per flight.[5] These figures are for the software employed on aircraft num-

5. The data available from the Air Force are based on false alarms per flight, not false alarms per flight hour. The Congressional Budget Office has not been able to determine whether the length and complexity of the flights generating the data have remained constant over time. Such changes could make the data appear more or less favorable than is merited.

bered 2 through 18. Results are even better for the software employed on subsequent aircraft. The false alarm rate has dropped from about 95 per flight to about three per flight. In addition, testing of the most recent software edition indicates the false alarm rate might fall to as low as one per flight.

The rate of false alarms regarding the offensive avionics has dropped from an average of 17 per flight to about nine per flight. Flight test data on the most recent software indicate the rate might drop to about two per flight. That version was installed on the B-1Bs in February 1988.

The portion of CITS that monitors the defensive avionics, however, is not yet performing well. Part of the problem has been that an early software error prevented all but about six of more than 250 maintenance codes for the defensive avionics from being generated. In addition, work has been held back by the immature state of the defensive avionics system. Indeed, further progress on CITS for that system will now depend on how the Air Force chooses to modify the defensive avionics following its current review.

Reports that the B-1B is Overweight

Many reports in the press have claimed that the B-1B is 40 tons overweight and, as a result, cannot fly high enough when cruising and refueling.[6] But these reports are misinformed.

The B-1B is not overweight. The B-1A had a designed empty weight of 174,300 pounds, while the B-1B has an empty weight of approximately 182,360 pounds. Thus, the B-1B is about 8,000 pounds (4.6 percent) heavier than the B-1A. But this extra weight results in part from structural changes that enable the B-1B to carry a larger payload internally and cruise missiles externally. Of the 8,000-pound increase in weight, about 1,300 pounds is attributable to changes in structure, 800 pounds to changes in propulsion, 2,500 pounds to changes in offensive and defensive avionics, and the rest to changes in other systems.

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6. See, for example, "The B-1 Bomber: A Flying Lemon," *U.S. News and World Report* (November 24, 1986), p. 29; and "Debut of the Wrong Bomber," *New York Times*, December 12, 1986.

As a result of these structural changes, the B-1B could carry about 30,000 more pounds of fuel and munitions than the B-1A on the high-altitude portions of a penetrating mission. In addition, whereas the B-1A was not designed to carry munitions externally, the B-1B could carry up to about 50,000 pounds of munitions externally, enabling it to carry air-launched cruise missiles on a standoff mission.

Two other questions have been raised about the B-1B's payload capacity: Does flying at greater weights decrease the B-1B's optimum cruise altitude and, if so, is the lower cruise altitude a problem? Does flying at greater weights affect aerial refueling?

Optimum Cruise Altitude. When flying from the United States to a distant target, it is advantageous to fly at a speed and altitude that maximize fuel efficiency, thereby increasing the bomber's range and decreasing the demand for aerial refueling. If the B-1B exploits its structural weight-carrying capacity and flies with more fuel or munitions, the optimum cruise altitude decreases (see Figure 7).

This decrease in optimum cruise altitude, however, is basically irrelevant to the bomber's ability to perform its mission. Flying at 20,000 feet while en route to the Soviet Union is no more dangerous than flying at 35,000 feet. Once the bomber is within range of Soviet air defenses, of course, it would switch to a low-altitude approach.

Aerial Refueling. To reach targets in the Soviet Union, the B-1B must be refueled en route from a tanker aircraft. It is preferable to refuel at altitudes above approximately 20,000 feet since, below that level, the bomber and its tanker are more likely to have to fly through clouds, precipitation, and turbulent air, which can complicate the process of transferring fuel. In addition, fuel efficiency generally improves at higher altitudes.

The B-1B, when equipped with the basic flight control system, cannot always refuel above 20,000 feet. The refueling altitude falls below 20,000 feet when the B-1B's weight exceeds 350,000 pounds (see Figure 8). At 430,000 pounds, the refueling altitude drops to between 10,000 and 13,000 feet.

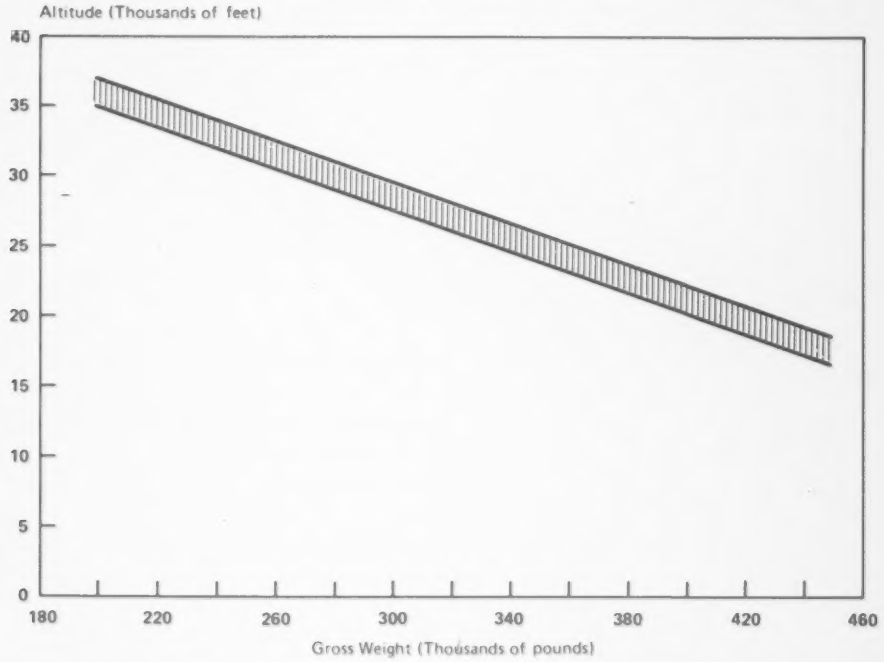
This situation is being improved, however, by the deployment of the Stall Inhibitor System on the B-1B. For example, at a velocity of

368 miles per hour and a gross weight of 400,000 pounds, the B-1B equipped with SIS is able to refuel at nearly 20,000 feet rather than at about 14,000 feet (see Figure 8).

Ice Damage to Engines

The B-1B has an anti-icing system that attempts to prevent ice from building up in flight at places where it might break loose and enter the engines. Ice has been building up in some unanticipated places on the B-1B, however, then breaking loose and damaging fan blades in the

Figure 7.
B-1B's Optimum Cruise Altitudes as a Function of Gross Weight

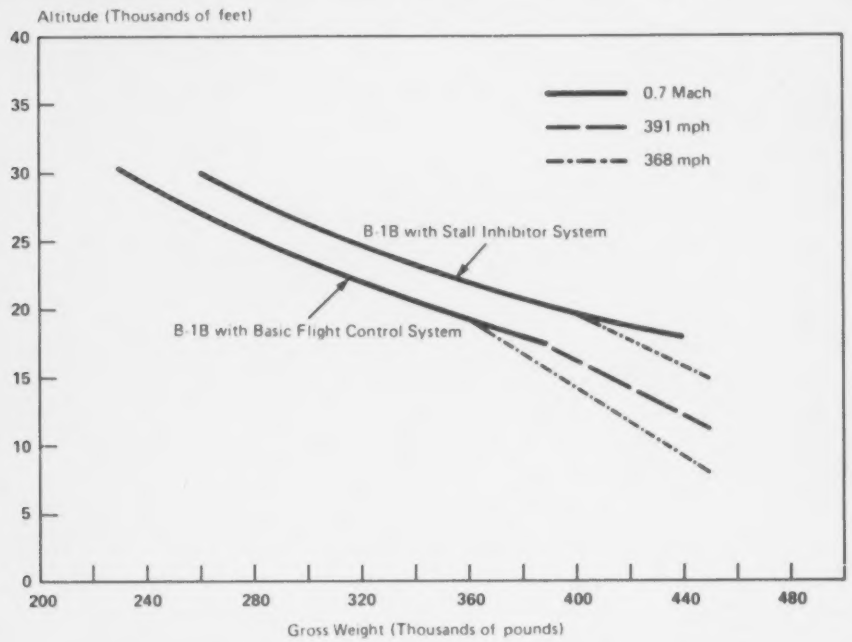


Source: Congressional Budget Office analysis of data from the U.S. Air Force.

first stage of the engines. This ice buildup creates a maintenance problem since damaged blades must be replaced. Although the ice has not yet damaged an engine enough to endanger an aircraft or prevent it from completing a wartime mission, the ice presents at least a small risk of such results.

The Air Force has conducted wind-tunnel tests to study this problem. Based on those tests, which were completed in June 1988, the service is designing an improved system for preventing ice buildup. A prototype is scheduled to be installed on a B-1B for tests in November

Figure 8.
B-1B's Refueling Altitudes as a Function of Gross Weight



Assumptions: Bomber is flying with 25-degree wing sweep and maintaining the ability to pull up at 1.3 g's without exceeding a safe angle of attack.

SOURCE: U.S. Air Force.

1988. Pending deployment of this improved system, the B-1Bs on training missions are permitted to fly only for a limited number of minutes under conditions that could cause ice to form on the plane.

Preparation for Conventional Missions

During testimony in support of development and procurement of the B-1B, the Air Force indicated that it would prepare the B-1B to conduct conventional missions as well as strategic nuclear missions.[7] The Air Force has fulfilled this commitment by certifying the B-1B's capability to carry conventional bombs.

Some analysts argue, however, that this certification is only symbolic. For the B-1B to have a significant conventional role, the Air Force needs to procure standoff munitions and War Readiness Spares Kits--neither of which are funded in the current Air Force budget.

Standoff munitions are needed because the B-1B is too valuable for the risky mission of flying over a target and dropping conventional bombs. Because of the risks inherent in dropping bombs, for example, the Air Force is planning to field precision-guided standoff munitions for its B-52G bombers assigned to conventional missions.[8] The Air Force states that it does not have a plan for providing such munitions for its B-1B bombers.

If the Air Force intends to make the B-1B available for multiple conventional sorties in an extended conventional conflict, it would probably need kits of spares to support the surge in demand for parts.[9] The Air Force has no funds budgeted to procure such kits for the B-1B.

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7. See testimony by Lt. General Kelly H. Burke, *Strategic Force Modernization Programs*, Hearings before the Subcommittee on Strategic and Theater Nuclear Forces of the Senate Committee on Armed Services, 97:1 (1981), p. 330.

8. See testimony by Major General Michael Loh, *Department of Defense Authorization for Appropriations for Fiscal Years 1988 and 1989: Part 4, Strategic Forces and Nuclear Deterrence*, Hearings before the Senate Committee on Armed Services, 100:1 (1988), pp. 2079-2081.

9. In 1981, the Air Force compared the potential conventional use of the B-1B to the use of B-52 bombers in Vietnam and B-29 bombers in Korea, where aircraft flew multiple conventional sorties. See testimony by Lt. General Kelly H. Burke, *Strategic Force Modernization Programs*, Hearings before the Subcommittee on Strategic and Theater Nuclear Forces of the Senate Committee on Armed Services, 97:1 (1981), p. 330.

Thus, the B-1B is currently ill-prepared for many conventional conflicts where the targets are well defended or multiple sorties are required. As currently configured, the bomber could be used for single sorties against poorly defended targets, but the Air Force has a number of other aircraft well suited to that task.

Problems with Carrying Cruise Missiles Externally

The Air Force conducted five flight tests of the B-1B between December 1987 and July 1988 to analyze its ability to carry advanced cruise missiles externally.[10] These tests revealed that when the B-1B bomber is flying at low altitudes and high speeds, some of these missiles were subjected to acoustic levels of up to 165 decibels. The ACM was designed to withstand only 162 decibels, however, raising concerns that the B-1B might not be able to carry ACMs externally.

These concerns are probably not justified. At the higher altitudes and slower speeds characteristic of flights with cruise missiles, the acoustic levels were lower than those noted above (the acoustic level is highly dependent on air density and aircraft velocity). Thus, the acoustic levels generated outside the B-1B may not pose any problem for ordinary standoff or shoot-and-penetrate missions conducted with cruise missiles.

In addition, the external acoustic levels vary considerably with the cruise missile stations. The missiles are carried in three rows of four missiles each under the fuselage. The acoustic level is higher in the rear row than in the middle row and is higher at the outside of the rear row than at the inside. Thus, if there is an acoustic problem on normal missions with external cruise missiles, it might be solved by removing the two outside aft cruise missiles and carrying only 10 cruise missiles externally rather than 12.

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10. The Air Force may have tested the ACM rather than the ALCM-B for two reasons. First, since the Air Force does not plan to carry cruise missiles on the B-1B until well into the 1990s, and possibly the end of the 1990s, the B-1B would probably be deployed with the ACM rather than the ALCM-B. Also, since the ACM is only beginning to enter production, the Air Force might still be able to make engineering changes in the missile that would facilitate carrying it externally.

Problems with Launching the SRAM-A

Launching SRAM-A missiles from the rear bay has been complicated by turbulence under the aircraft that causes the SRAMs to pitch down to such a degree that they cannot recover to perform their mission. In February 1988, the Air Force tested potential remedies. A workable solution has been found that consists of repositioning the doors of the middle bay (leaving them further open or closed) and the spoiler (a panel that drops down in front of each bay) to change the dynamics of the turbulence.

Problems with Launching Conventional Bombs

As noted above, the Air Force has given the B-1B the capability to carry some conventional bombs, one of which is the Mk-82. A problem has emerged, however, in carrying that munition--the bomb rack cannot be loaded safely without cumbersome procedures. The Air Force has therefore redesigned the bomb rack. Flight tests of the new rack began in April 1988, and certification is planned for autumn 1988. There has also been a problem in dropping the Mk-82 from the rear bay. The Air Force has found that opening the doors of the middle bay has solved the problem. Tests of dropping the Mk-82 from all three bays were conducted in March 1988 and confirmed that the solution is adequate.

Bird Strikes

On September 28, 1987, a B-1B bomber engaged in low-altitude training struck a large bird and crashed, killing three crew members.[11] The bird apparently hit the support between one set of engines and a wing, ripping through the bomber's skin and destroying various fuel and hydraulic lines.

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11. Three crew members, who were in ejection seats that functioned correctly, survived the accident. One crew member whose seat did not function correctly, and two who were not in ejection seats, died in the crash.

The Air Force immediately suspended low-altitude training and, after investigating the accident, decided to strengthen three vulnerable points on the B-1B bombers: the support structure connecting the engine nacelle to the wing (a steel and kevlar shield is placed under the skin); the base of the tail of the aircraft (a steel shield is placed under the skin to protect the actuator for the horizontal stabilizer); and the point where the movable wings join the fuselage (a kevlar curtain is attached to the fuselage). A total of 31 B-1Bs had received this modification as of July 1988. On the current schedule, all aircraft will be modified by February 1989.

Other Problems

As expected with a complicated weapons system, various problems have emerged with individual parts. For example, one particular electrical generator has repeatedly failed, and some windshields have delaminated. Fixing such problems is part of the ongoing maintenance necessary to keep the B-1B operational.

SUMMARY

The Air Force has made progress in resolving the B-1B's major problems and host of minor problems. The service anticipates that most of the work necessary to solve these problems will be completed within the original $20.5 billion cap (1981 dollars).

Despite progress, however, several of the B-1B's problems may not be solved on the anticipated schedule. It is too soon to predict with confidence that the Stability Enhancement Function for the flight control system will perform as predicted and will be completed in accordance with the planned schedule and budget. Also, following the recent revelation that the architecture of the defensive avionics system has a major deficiency, the Air Force's plan for modifying the system to meet the baseline specifications and installing it by 1992 is in disarray. A new schedule and budget for the defensive avionics system must await completion of the Air Force's study of alternatives. Until these programs are completed, the B-1B's payload, range, and defensive capability will fall short of planned levels.

Even so, there is little controversy over whether work on the baseline B-1B should proceed: the Air Force has carefully prepared the plans for resolving the B-1B's problems, and--with the possible exception of the defensive avionics system--relatively small amounts of funds are at stake. Instead, the significant issue is the appropriate funding level for and direction of enhancements that might eventually provide the B-1B with capability beyond that in the original plans.

CHAPTER III

THE CAPABILITY OF SOVIET AIR DEFENSES AND THE COMPARATIVE MERITS OF PENETRATING AND STANDOFF BOMBERS

Over the next few years, the Congress will have to decide whether to invest substantial additional monies in the B-1B bomber program to enhance the aircraft's ability to penetrate Soviet air defenses and to make it useful in a wider range of combat missions. The value of those enhancements depends on how the United States plans to use the B-1B bomber. Will the bomber be maintained as a penetrator, shifted to a "shoot-and-penetrate" role in which it launches externally carried cruise missiles before penetrating Soviet defenses, or employed as a standoff bomber carrying only cruise missiles?

The choice of how to use the B-1B depends in turn on answers to two basic questions:

- How effective are Soviet air defenses, and how much might they improve in the future?
- What are the advantages of employing the B-1B as a penetrating bomber as opposed to a standoff bomber?

This chapter discusses these two issues as background for considering enhancements to the B-1B that may be proposed in future years.

SOVIET AIR DEFENSES

The Soviet Union's air defenses include surface-to-air missiles (SAMs), fighters carrying air-to-air missiles, and anti-aircraft guns. These assets are supported by a ground-based radar network and airborne radars.

The current Soviet air defense system has had three significant shortcomings. Most important, many portions of the Soviet air defense network, including airfields and ground-based radars, are

vulnerable to destruction by U.S. ballistic missiles, which would arrive long before U.S. bombers. Also, the effectiveness of Soviet air defenses is limited by the short range of ground-based radars and the limited ability of fighter aircraft to find low-flying penetrators. These shortcomings have enabled the United States to maintain confidence that a significant percentage of its bombers can penetrate Soviet air defenses and accomplish their missions.

Two factors, however, have refocused attention on the effectiveness of Soviet air defenses. First, the B-1B was deployed with defensive avionics that fall far short of planned capabilities. Second, the Soviet Union is striving to remedy the shortcomings in its air defenses by decreasing its dependence on land-based facilities, deploying longer-range tracking radars on aircraft, deploying "look-down/shoot-down" fighters, and improving its surface-to-air and air-to-air missiles.

How effective are current and planned Soviet air defenses? Evaluations vary widely, depending on the scenario. Two scenarios--one in which the B-1B penetrates easily and the other in which it does not--are presented below. These scenarios reflect differences in circumstances (for example, whether the United States is attacked with or without warning) and in emphasis (for example, using the best-case rather than worst-case assumptions regarding such factors as weapon performance or the impact of a precursor attack on the Soviet command system). They also reflect differences in tactics (such as whether cruise missiles would be used to help destroy Soviet defenses and whether the chosen targets are defended). Depending on the circumstances, emphasis, and tactics considered, the B-1B can appear to be either an effective or ineffective penetrator.

After evaluating these factors in the light of the best available information--including the tactics used in the Strategic Integrated Operational Plan (SIOP, the U.S. blueprint for conducting strategic warfare), and assumptions based on U.S. intelligence data--the Air Force concluded that an acceptable percentage of B-1Bs would succeed in penetrating heavily defended areas well into the 1990s.[1] Because of

1. See testimony by General B. L. Davis, Commander in Chief of the Strategic Air Command, in *Strategic Force Modernization Programs*, Hearings before the Subcommittee on Strategic and Theater Nuclear Forces of the Senate Committee on Armed Services, 97:1 (1981), p. 264.

the problems encountered in fielding the defensive avionics for the baseline B-1B, the percentage of B-1Bs that would penetrate Soviet defenses under almost any given set of assumptions would be lower now than when the Air Force made that evaluation. The Air Force might be able to raise the probability of penetrating Soviet defenses, however, by changing the tactics or the difficulty of the mission, as discussed below.[2]

One Scenario: B-1B Bombers Penetrate Easily. In this scenario, it is assumed that the United States would have time to enhance the survivability of its strategic forces before a Soviet nuclear attack on the United States.[3] Measures to increase survivability might include deploying bombers to a larger number of airfields or placing them on airborne alert and sending all available submarines carrying ballistic missiles to sea. The United States might also prepare to launch its silo-based intercontinental ballistic missiles on warning of a Soviet attack so that they would not be destroyed on the ground.[4]

Thus, a large number of U.S. strategic nuclear weapons would survive a nuclear attack. Some of the warheads on surviving ballistic missiles probably would be dedicated to suppressing Soviet air defenses--attacking such targets as major military airfields, with the intention of destroying Soviet interceptors and their support facilities. As a collateral product of attacks planned and conducted for other rea-

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2. The Institute for Defense Analyses is currently estimating the percentage of B-1Bs that would penetrate Soviet air defenses under specific sets of assumptions. A classified report to the Congress is expected in October 1988.

3. This assumption is based on the argument that a political confrontation would precede a Soviet nuclear attack since, given the risks inherent in nuclear war, the Soviet Union would not consider using nuclear weapons unless major national interests were at stake and other potential solutions had been explored. During an escalating political confrontation, the United States would have time to place its forces on alert. Also, even if a political confrontation did not precede the Soviet attack, U.S. intelligence data might reveal preparations for such an attack, giving the United States time to place its forces on alert.

4. Many analysts doubt the wisdom of attempting to launch ICBMs on warning of a Soviet attack since, if the United States erred in identifying a perceived Soviet attack, it could start a major nuclear war. Such an error is not inconceivable; several incidents have triggered a false indication of a nuclear attack. In one case, the false indication was caused by a malfunctioning computer chip and, in another, by a technician who loaded a test tape with a simulated attack into a computer without making the appropriate notifications. See *Recent False Alerts from the Nation's Missile Attack Warning System*, Hearings before the Senate Committee on Armed Services, 96:2 (1980); and *Failures of the North American Aerospace Defense Command's (NORAD) Attack Warning System*, Hearings before the Subcommittee on Legislation and National Security of the House Committee on Government Operations, 97:1 (1981).

sons, many other airstrips, radars, and surface-to-air missile sites in the Soviet Union probably would be destroyed.

In this scenario, therefore, many Soviet interceptors would be destroyed on the ground, and others might survive but--because the support facilities had been destroyed--would run out of fuel before U.S. bombers arrived. In addition, U.S. bombers would fly routes designed to take maximum advantage of the direct and indirect damage to Soviet air defenses, facilitating their penetration of those defenses. Also, since most Soviet strategic SAMs are not mobile, the B-1Bs' routes would be planned to avoid them.

In this scenario, the challenge posed to penetration by the B-1B would be small. Moreover, the effectiveness of Soviet air defenses could be diminished further by the potential effects of high-altitude electromagnetic pulse and failures in the Soviet command system.

High-altitude electromagnetic pulse (HEMP) is a burst of radio energy generated when gamma rays from an exoatmospheric nuclear explosion collide with the upper atmosphere. This pulse can cause a high-voltage surge of electricity in conductive materials, which can burn out electrical components. Although the B-1B has been designed to resist HEMP, HEMP might damage Soviet radars and missile guidance systems if they have not been similarly protected.

Failures in the Soviet command system could also degrade the performance of the Soviet air defenses. Such failures might include communication equipment damaged by HEMP; satellite and high-frequency radio communications disrupted by blackouts (the absorption of radio signals) and scintillation (the rapid fluctuation in the strength of radio signals) caused by nuclear detonations; and command centers destroyed by nuclear blasts. Damage to the command system would complicate the coordination of Soviet defenses, making it easier for bombers to penetrate them.

One could also argue that Soviet air defense technology will probably not present major challenges to the B-1B's ability to serve as a penetrating bomber through the 1990s. Consider, for example, airborne radars on Soviet AWACS (Airborne Warning and Control System) aircraft, improved missiles, and the potential to intercept bombers farther from Soviet borders. Soviet AWACS have many

advantages over ground-based radars but could be highly vulnerable to attacks by fighter aircraft. Nor does deployment of any other effective wide-area tracking system appear imminent (see Appendix B). Although the Soviet Union is deploying more fighter aircraft with the ability to track and attack low-flying bombers, the missiles that the fighters would fire do not appear to be gaining a significant advantage over countermeasures designed to defeat the missiles. Finally, in regard to intercepting bombers farther from its borders, which could give the Soviet Union more time to down bombers before they reach the Soviet borders, no leap in capability appears imminent.

A Second Scenario: The B-1B is Highly Vulnerable. A more pessimistic scenario starts with a different assumption--that the Soviet Union might catch the United States off-guard with a surprise attack, destroying ICBMs in their silos, submarine-launched ballistic missiles on submarines that are in port, and many bombers before they can take off. Thus, the United States would have fewer surviving strategic warheads and might not have enough to allocate some to the task of suppressing Soviet air defenses. Even if some warheads were allocated to that task, the effects might be minimal: the effects of HEMP are uncertain; the Soviet Union might succeed in launching its fighters before U.S. missiles arrived and in refueling them with tanker aircraft or at remote airfields; and the destruction of a few ground-based radars, out of about 10,000 the Soviet Union has deployed, would make no practical difference in Soviet radar coverage. Therefore, in comparison to the previous scenario, fewer U.S. bombers would face a more robust Soviet air defense system.

The predicted success rate of B-1B bombers in penetrating Soviet defenses would decrease further if one used the highest estimates of the effectiveness of Soviet radars and missiles and the lowest estimates of the reliability and accuracy of U.S. weapons and of the effectiveness of U.S. countermeasures (chaff, flares, and electronic countermeasures).

Moreover, the effectiveness of the B-1B bombers depends on the choice of specific missions and tactics. For example, the B-1B's probability of successful penetration would be lower if the selected targets were heavily defended or if the mission was planned such that the B-1B used bombs to attack targets rather than SRAMs, necessitating that it fly over its target. Cruise missiles and short-range attack

missiles could be used to suppress defenses as well as to attack targets directly; less than optimal allocation to either task would also lower the B-1B's effectiveness.

Finally, the Soviet Union is continuing to invest heavily in its air defenses. Those defenses could improve substantially as the Soviet Union deploys more interceptors with the ability to detect and attack low-flying bombers and more AWACS for coordinating air defenses over a wide area. These Soviet AWACS might prove to be more effective and difficult to destroy than assumed in the previous scenario.

ADVANTAGES OF PENETRATING AND STANDOFF BOMBERS

The ability of the B-1B to penetrate Soviet defenses is one factor in determining whether to maintain it as a penetrating bomber or to employ it as a standoff bomber that carries cruise missiles. Another factor, of equal importance, is the relative advantage of penetrating and standoff missions. The Air Force argues that penetrating Soviet air defenses with manned bombers provides capabilities that cannot be realized by launching cruise missiles from a bomber flying outside Soviet territory. On the other hand, proponents of standoff bombers contend that many of the Air Force's arguments do not stand up and that cruise missiles are both less expensive and more effective in most missions. This section reviews these opposing views in greater detail after briefly noting some advantages offered by bombers regardless of their mission.

Advantages of Bombers

Penetrating and standoff bombers share some very important advantages that are worth noting to ensure they do not become part of the debate regarding the desirability of the two types of bombers.

- Bombers are considered to contribute more to stability during a crisis than ICBMs or SLBMs. Because bombers are slow, taking many hours to reach the Soviet Union (compared with 15 to 30 minutes for ballistic missiles), they are

ineffective tools for conducting a first-strike nuclear attack that would destroy many Soviet weapons, command centers, and communication systems, diminishing Soviet capability to retaliate. For this reason, bombers do not create an incentive for the Soviet Union to prepare to launch its ICBMs on warning of an attack, or to attack in the belief that the United States is preparing such a first strike.

- For several hours after bombers take off en route to the Soviet Union, the Air Force can contact the bombers and cancel a mission. In contrast, ICBMs and SLBMs cannot be recalled once they are launched.

- Bombers are vulnerable if a nuclear warhead detonates at an airfield when they are on the ground, but this vulnerability can be greatly reduced by placing a high percentage of the bombers on strip alert (parked near the runway ready to take off), dispersing them from main operating bases to secondary bases, or placing some on airborne alert.

- The U.S. Administration could send a visible message to the Soviet Union regarding the seriousness of a situation, while stopping well short of war, by changing the alert level of bombers.

- There is a potential synergistic relationship between the survivability of bombers and ICBMs in that, if the Soviet Union configures an attack to maximize the probability of destroying U.S. bombers, the probability of destroying U.S. ICBMs would be diminished, and vice versa. This relationship is explained in more detail in Box 4.

- In an extended nuclear war, bombers could deliver one load of nuclear munitions and then return to pick up a second load, assuming the necessary facilities have survived.

- Bombers can be employed in conventional as well as nuclear conflicts by loading them with different munitions.

BOX 4
Synergistic Relationship Between ICBMs and Bombers

Analysts have long pointed to a potential synergistic relationship between intercontinental ballistic missiles (ICBMs) and bombers. The argument is that, if the Soviet Union configures an attack to maximize the probability of destroying U.S. bombers, the probability of destroying U.S. ICBMs would be diminished, and vice versa.

The first contention--that a Soviet attack configured to maximize the destruction of U.S. bombers would increase the percentage of U.S. ICBMs that would survive--assumes that the Soviet Union would decrease the bombers' warning time by launching its submarine-launched ballistic missiles (SLBMs) and ICBMs simultaneously, with the inaccurate Soviet SLBMs attacking U.S. bomber bases and the accurate Soviet ICBMs attacking U.S. ICBMs. Thus, U.S. bombers would only have about 15 minutes--the flight time of the SLBMs--of warning time to escape their bases. Under this strategy, however, the United States might have time to confirm the detonation of Soviet SLBM warheads on U.S. territory and to launch U.S. ICBMs in retaliation before Soviet ICBMs arrive to attack them.

The second contention--that a Soviet attack configured to maximize the destruction of U.S. ICBMs would increase the percentage of U.S. bombers that would survive--assumes that the Soviet Union would time the launch of its ICBMs and SLBMs so that they would arrive on their respective targets simultaneously. With this strategy, U.S. bombers would have more warning time, and more bombers would escape their bases before the attacking missiles arrived. Because no Soviet SLBM warheads would detonate on U.S. territory before the Soviet ICBMs arrived to attack U.S. ICBMs, however, there is a lower probability that the United States would launch its ICBMs in time to save them. This argument assumes that the United States would hesitate to launch its ICBMs since the evidence of the Soviet attack would be weaker; if the United States launched its ICBMs and its perception of the Soviet attack was incorrect, the United States would have needlessly started a major nuclear war.

Some of the conditions assumed in these scenarios are changing. The scenarios assume, for example, that Soviet SLBMs are too inaccurate to attack U.S. silo-based ICBMs. The accuracy of Soviet SLBMs is improving, however, and they might eventually have a high probability of destroying U.S. silo-based ICBMs. The scenarios also assume that the Soviet Union would launch its SLBMs from close to the United States. As the range of Soviet SLBMs has increased, however, the Soviet Union has tended to keep its SLBM-carrying submarines farther from U.S. shores, increasing their survivability and flight time and thus reducing the distinction between the flight time of SLBMs and ICBMs.

The Case for the Penetrating Bomber

While both penetrating and standoff bombers possess the advantages noted above, advocates of penetrating bombers contend that such bombers have additional advantages that cannot be duplicated by standoff bombers equipped with cruise missiles. These advantages include a superior ability to:

- Attack hardened targets;
- Conduct damage assessment/strike missions;
- Attack mobile or relocatable targets;
- Defeat terminal Soviet air defenses; and
- Deliver conventional munitions.

The penetrating bomber also offers advantages under counting rules being proposed during the Strategic Arms Reduction Talks (START).

The Hard-Target Mission. The penetrating bomber can effectively attack targets hardened against nuclear blasts because it can carry large bombs and deliver them accurately. Cruise missiles cannot currently match this capability. Although they are accurate, they cannot carry bombs with the large yields that bombers can carry. The currently deployed ALCM-B carries one W80-1 warhead with a reported yield of about 200 kilotons (kt). The B-1B can carry a variety of bombs including the B61 (reported yield of 100 to 500 kt) and the B83 (reported yield in excess of 1,000 kt).[5]

The Damage Assessment/Strike Mission. It is conceivable that in a U.S. nuclear attack on the Soviet Union, some targets would be targeted with a ballistic missile warhead and then, hours later, U.S. bombers could fly over the targets to determine (using high-resolution radar) whether the targets were destroyed. If they were not destroyed,

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5. For the yield of warheads, see Thomas B. Cochran, William M. Arkin, and Milton M. Hoenig, *Nuclear Weapons Databook, Volume I: U.S. Nuclear Forces and Capabilities* (Cambridge, Mass.: Ballinger, for the Natural Resources Defense Council, Inc., 1984), pp. 65, 175, and 199.

the bombers would be authorized to attack them again using either a bomb or a SRAM.

Strategic Relocatable Targets. The Air Force argues that penetrating bombers are well-suited for attacking a growing category of mobile targets collectively called strategic relocatable targets (SRTs). This category includes diverse assets such as trains, ships, planes, mobile ICBMs, and armies maneuvering out of garrison.

This group of targets has attracted interest because, as the accuracy of U.S. ballistic missiles has improved, the Soviet Union has put greater reliance on mobility to maintain the survivability of important sensors, command centers, and weapons. For example, the Soviet Union is deploying the rail-mobile SS-24 ICBM and the road-mobile SS-25 ICBM, possibly in response to the pending deployment by the United States of the highly accurate MX ICBM and Trident II SLBM.

The Air Force contends that the United States should be able to target such SRTs to deter a Soviet decision to employ nuclear weapons. The argument that this capability will increase deterrence has two components. The first component is that this capability would prevent the Soviet leaders from initiating a war against the United States with the expectation that the Soviet Union would have a survivable reserve of strategic nuclear weapons with which it would be able to pressure the United States for concessions. The second component is based both on current U.S. strategic policy, which contends that deterrence is strengthened by the ability to threaten the facilities that the Soviet leaders value highly, and on the assumption that Soviet leaders clearly value those assets, such as mobile ICBMs, that they have taken great efforts to protect.

The Air Force argues that the penetrating bomber is well suited for attacking such mobile targets for two reasons: the bomber carries both sensors and weapons, eliminating the problem of communicating between a sensor platform and a weapon platform; and the bomber crew can make the final identification of a mobile target before attacking it.

Terminal Defenses. A cruise missile approaches a target at a low altitude and slow speed. A penetrating bomber, on the other hand, can either approach the target at a low altitude and drop bombs or by-pass

the target and fire short-range attack missiles, which are difficult to intercept because they approach the target at a high speed and a high angle. Thus, the penetrating bomber, compared with cruise missiles, has a better chance of overcoming terminal defenses.

Furthermore, the Air Force argues that cruise missiles and penetrating bombers, in combination, present the Soviet Union with a diverse threat that forces the Soviet Union to expend greater resources on air defense, reducing the resources available to meet other military requirements.

Conventional Missions. A penetrating bomber designed to carry nuclear munitions through Soviet air defenses can also be well qualified to carry conventional munitions on a penetrating mission. Thus, the B-1B, if maintained as a penetrating strategic bomber, could be available for use as a conventional bomber in other parts of the world.

Arms Control. In the START negotiations, the United States and the Soviet Union have tentatively agreed to a ceiling on strategic warheads under which bombs and SRAMs would be discounted. Specifically, rather than each bomb or SRAM counting as one warhead, all of the bombs and SRAMs on a penetrating bomber would count as a single warhead.

The general rationale for discounting the bombs and SRAMs carried on penetrating bombers is that penetrating bombers must traverse Soviet air defenses, creating the possibility that a significant percentage will not reach their destination. Also, a bomber on a mission might only carry one-third to two-thirds of the bombs and SRAMs it is theoretically capable of carrying. For both reasons, if the counting rules credited a bomber with carrying as many warheads as it can carry, the counting rules would overcount the relative strength of the bomber force. Finally, it might make sense to discount bombs and SRAMs to encourage their deployment, since weapons on a bomber do not pose the same first-strike threat as the warheads on a ballistic missile, which can reach a target in the Soviet Union in 15 to 30 minutes rather than 8 to 14 hours.

Since this discount would not apply to air-launched cruise missiles (a bomber equipped to carry cruise missiles would be counted as carrying some larger number of warheads yet to be negotiated), the United

States could retain more warheads by deploying penetrating bombers armed with bombs and short-range missiles than it could by deploying standoff bombers armed with cruise missiles. According to press reports, the United States' negotiating team is seeking to have each bomber equipped to carry cruise missiles count as about 10 warheads under the warhead ceiling.

The Case for the Standoff Bomber

The proponents of standoff bombers present three basic points. First, standoff bombers with cruise missiles are more effective than penetrating bombers and are also less expensive. Second, it would not serve U.S. interests to favor penetrating bombers over standoff bombers in future arms control agreements. Third, there are no special missions--hard-target missions, damage assessment/strike missions, SRT missions, and conventional missions--for which penetrating bombers are better suited than cruise missiles.

Greater Effectiveness. Proponents of standoff bombers contend that cruise missiles launched from standoff bombers can do a better job of penetrating current and future Soviet air defenses than penetrating bombers.

Cruise missiles exploit three weaknesses in Soviet defenses. They fly low to the ground beneath the coverage of ground-based radars; with stealth technology, they will be difficult for future Soviet AWACS and fighters with look-down radars to detect; and, perhaps most important, they inundate defenses. A single Soviet fighter, for example, could destroy perhaps 16 warheads by intercepting a penetrating B-1B bomber, but the fighter has little hope of intercepting more than one or two of the up to 20 cruise missiles that can be launched by the B-1B operating as a standoff bomber.

In addition, if the Soviet Union attempts to intercept standoff bombers before they release their cruise missiles, the United States could employ many simple countermeasures. It could delay the attack (which might leave Soviet interceptors running out of fuel while flying over the ocean), increase the range of the cruise missiles (which might force the Soviet interceptors to fly out so far they have little time to intercept the bombers before running out of fuel), or alter the bombers'

routes so that they approach the Soviet Union from directions that are more poorly defended.

Moreover, there is a great deal of future flexibility inherent in cruise missile technology. For example, the United States is working on an earth-penetrating warhead for a cruise missile that would make it a more effective weapon against underground facilities and ICBM silos. Cruise missiles can also be used in tandem, with one detonating to destroy concentrated air defenses while the second follows to attack the primary target. In addition, the guidance and flight control system of cruise missiles can be improved so that, instead of following fairly direct paths to their targets, they take more deceptive routes. The payload aboard cruise missiles could also be altered so that several missiles within a larger group would serve as decoys to draw Soviet interceptors away from the rest.

Cost Effectiveness. If the United States were only to pursue a standoff capability in the future, relying on the ability of its B-52 and B-1B bombers to carry cruise missiles, it would be able to save money by canceling both the SRAM II program, which is developing an improved short-range attack missile, and the B-2 stealth bomber. The B-52 is aging, however, and if the United States needed more than 100 standoff bombers, it might eventually have to build a new bomber to carry cruise missiles. But a new bomber designed to stand off and launch cruise missiles would be cheaper than building the B-2, since it would not have to be designed for the demanding task of penetrating Soviet defenses. Also, the new bomber could be configured to eliminate the need for refueling by tanker aircraft, which are an expensive component of the current system of penetrating bombers. Finally, stealth technology might be more easily and cheaply incorporated in cruise missiles than in penetrating bombers, because cruise missiles are small and do not need cockpits, bomb bays, and landing gear (cavities and discontinuities in the skin are a major challenge in reducing an aircraft's radar cross section).

Arms Control. As noted earlier, the proposed strategic agreement under discussion in Geneva counts a penetrating bomber as only one warhead under the warhead ceiling but counts a bomber equipped to carry cruise missiles as carrying some higher, yet to be negotiated, number. This formulation could be considered advantageous to the United States, since the United States has more penetrating bombers.

Supporters of cruise missiles could argue, however, that the proposed agreement actually favors the Soviet Union by forcing the United States to pursue the more expensive, less effective strategy of deploying penetrating bombers instead of the cheaper, more effective strategy of deploying standoff bombers. (Indeed, this interpretation would fit with the long-standing Soviet aversion to permitting the deployment of long-range cruise missiles in a strategic arms agreement.) If so, perhaps the United States should change course and pursue an agreement that treats penetrating and standoff bombers equally so as not to preclude a future decision to opt for standoff over penetrating bombers.

The Hard-Target Mission. Attacking hardened targets is one of several missions for which the advocates of penetrating bombers claim the penetrating bomber is better suited than cruise missiles launched by standoff bombers. Proponents of standoff bombers, however, contend that the claims in support of penetrating bombers on these special missions are overstated and the claims for cruise missiles understated.

Although a penetrating bomber can carry a bomb with a more powerful warhead than that carried on a cruise missile, this capability does not demonstrate that the penetrating bomber is a better weapon for attacking hardened targets. First, despite its smaller warhead, a cruise missile is about as effective as a bomb against many hardened targets because of its high accuracy. Based on public reports of its accuracy and yield, the ALCM-B would have about a 99 percent probability of destroying a target hardened to withstand a pressure of 500 pounds per square inch (psi), which is representative of medium-hard facilities such as munitions bunkers, leadership bunkers, and older Soviet ICBM silos. It would have about an 87 percent probability of destroying a target hardened to withstand a pressure of 5,000 psi, which is representative of very hard facilities such as newer Soviet ICBM silos and command centers buried deep underground.

Second, many hardened targets would be defended, making it likely that bombers would attack them with SRAMs rather than bombs, since SRAMs enable the bomber to bypass rather than fly over the target. Cruise missiles are more effective than the currently deployed SRAM-A, which has relatively poor accuracy, and might be as effective as the SRAM II now being developed.

Third, the capability of cruise missiles against hardened targets could theoretically be increased by equipping them with warheads that would penetrate into the earth and then detonate, rather than detonate as the cruise missile flies over a target. Such warheads would increase the amount of energy converted into shock waves traveling through the earth, increasing the warhead's destructive ability against hardened facilities such as underground command centers and ICBM silos. One potential drawback might be that the cruise missile would have to fly at higher altitudes approaching a target, making it easier to track.

Nevertheless, and perhaps most important, neither penetrating bombers nor standoff bombers equipped with cruise missiles may be the best weapons for attacking hardened targets such as silo-based ICBMs and command centers that might be used to coordinate a Soviet attack on the United States. If the goal is to prevent such an attack, accurate ballistic missiles like the MX ICBM and the forthcoming Trident II SLBM, which can reach the target in 15 to 30 minutes rather than in the 8 to 14 hours required by a bomber, may be preferable.

The Damage Assessment/Strike Mission. Advocates of standoff bombers argue that the special capability of penetrating bombers on damage assessment/strike missions is exaggerated. First, it might be difficult for a bomber to determine whether a facility, particularly a hardened underground facility, has been destroyed because much of the damage may be hidden. Second, flying over the target to determine whether it has been destroyed might expose the bomber to Soviet air defenses, decreasing the probability that the bomber would complete other parts of its mission.

Third, if a facility is important enough to justify risking a bomber in this fashion, then it is important enough to justify a simpler measure which is as or more effective: target the facility with a second warhead initially. If the target might contribute to a subsequent Soviet attack on the United States, planners might choose a fast-arriving ballistic missile warhead as the second warhead. If it is not important that the target be destroyed quickly, then it makes sense to use a cruise missile rather than a penetrating bomber to deliver the second warhead. This approach leaves the penetrating bomber free to

pursue other tasks and spares it from the high-risk task of flying over potentially defended targets at low altitudes.

Finally, if there is a pressing need for damage assessment, high-altitude intelligence planes might be better suited to the task than low-altitude bombers.

Strategic Relocatable Targets. It is also unclear that the penetrating bomber serves a vital function in relation to attacking mobile and relocatable Soviet facilities.

First, although the number of mobile and relocatable Soviet facilities is growing, developing the capability to target them may not be in the best interest of the United States. Mobile Soviet ICBMs capable of surviving a U.S. attack, for example, potentially have the same stabilizing function during a crisis as the highly survivable U.S. SLBMs. If a portion of the Soviet strategic forces is highly survivable, the Soviet leadership would have less concern during a crisis that the United States might attack the Soviet Union, decreasing the pressure either for preparing to launch ICBMs on warning of a U.S. attack or for considering the use of a preemptive strike. By alleviating this pressure, survivable Soviet mobile missiles decrease the probability that a crisis would escalate into nuclear war.

Moreover, even if the United States wants to target mobile missiles and other SRTs, the technology for doing so with a bomber is immature. Basic requirements that a bomber must meet to be effective against SRTs include:

- **Search Capability**. A bomber must have enough range, in combination with the swath of ground the sensors can see at any one point, to search a large amount of territory.

- **Sensor Capability**. The resolution (size of object a sensor can detect) and sensitivity of the sensors in their proposed operating modes must be high enough to distinguish between similar objects such as a truck carrying freight and a truck carrying a missile.

- **Cueing**. To search for a mobile target, a bomber needs an estimate of its location. Because a mobile target can move

large distances while the bomber is flying to the Soviet Union, however, the bomber might need to receive this estimate when close to the Soviet Union to keep the potential search area to a manageable size.

- **Target Recognition.** Because a bomber's sensors would provide voluminous data while a target search is under way, some form of computerized target recognition system is probably required to sort the data and alert a bomber crew to a potential target.

- **Ability to Distinguish Targets from Decoys.** The target recognition software and the crew must be able to distinguish actual missiles from decoys; also, they must not be deceived by simple countermeasures that change the radar and infrared properties of a mobile target.

- **Minimal Vulnerability to Air Defenses.** The altitude, speed, and radar emissions of the bomber during a search must not make it unduly vulnerable to air defenses, including anti-aircraft guns and tactical surface-to-air missiles.

The United States is a long way from being able to meet these basic requirements. Neither radar nor infrared sensors provide the required resolution; the needed target recognition software has not been developed; and current search systems would be vulnerable to decoys and simple countermeasures.

In addition, there are inherent challenges in using a bomber such as a B-1B as the sensor platform. If the bomber flies close to the ground at 200 to 400 feet to hide from enemy air defenses, the swath covered by its sensors is limited, increasing the distance the bomber must travel to search a given area. The demand for extended range is severe even when the search area is relatively small. For example, if the area being searched is the territory within 20 miles of where the mobile target was last detected and the sensors on the bomber have a clear view of the land 2,000 feet to either side of the bomber, then the bomber would have to fly about 1,700 miles to cover the search area.

On the other hand, if a bomber flies higher--say, at 1,000 feet--the sensors can cover a wider swath but the bomber is much more exposed

to detection by ground-based radars and vulnerable to anti-aircraft fire and surface-to-air missiles. In addition, if the bomber employs active sensors like radar, those sensors might alert the air defense forces to the bomber's presence.

Finally, the United States does not currently have a system of cueing--instructing a bomber where to search for a particular mobile target--that could decrease the size of the area the bomber must search. To establish such a system, the United States needs space-based sensors or other technical means for locating the mobile targets when they are deployed in the field. Once such sensors are developed and deployed, the United States needs a method to process the data and get it to the bomber while en route to the Soviet Union.[6] Thus, the United States is a long way from having the basic elements in place that will make a bomber such as the B-1B an effective weapon against targets such as mobile Soviet missiles.

Moreover, when the most difficult challenge--finding effective sensors--is met, it may become evident that bombers are not the preferred weapon for the task. For example, the sensors might operate best at medium or high altitudes and, if so, it might make more sense to carry them on expendable drones. If relatively precise data on the location of mobile missiles can be obtained from high-altitude reconnaissance aircraft or from satellites, the most reliable and inexpensive system for destroying mobile missiles might involve relaying the location to either ballistic missiles or cruise missiles.

Conventional Missions. Modern anti-aircraft guns and tactical surface-to-air missiles are now possessed by nations in many regions in the world, making it increasingly risky for a bomber to fly over a target and drop bombs.[7]

In conventional warfare, therefore, there is a growing effort to equip bombers to stand off from the target and attack it with pre-

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6. The MILSTAR satellite communication system is a candidate for the data link because the system will employ high frequencies that are relatively immune to disruption by the effects of high-altitude nuclear detonations.

7. Risk in conventional missions is commonly evaluated by a different standard than risk in nuclear missions. For example, 30 percent to 40 percent attrition might be considered a success for a strategic nuclear mission, while 5 percent attrition per sortie might be judged unacceptable for conventional missions.

cision-guided munitions such as glide bombs, short-range air-to-surface missiles, and cruise missiles. Since a standoff strategic bomber would be effective in performing these conventional missions, the demands of conventional warfare do not necessitate maintaining a strategic penetrating bomber.

This study cannot reconcile these many arguments and reach a conclusion about the desirability of penetrating bombers compared with standoff bombers. Indeed, as is the case with so many arguments about national defense, there is no clear answer. Nonetheless, questions about the desirability of retaining the capability to penetrate Soviet air defenses should be kept in mind as the Congress considers enhancements to the B-1B bomber.

CHAPTER IV

ENHANCEMENTS FOR THE B-1B BOMBER

A sophisticated weapon system like the B-1B bomber is never really complete. As the B-1B was being deployed, the Air Force began to analyze how to incorporate new technology to improve reliability, to adjust to changing defensive threats, and to expand the bomber's capability to penetrate Soviet air defenses. On the one hand, this ongoing analysis could lead to programs that lengthen the life and expand the role of the B-1B, squeezing more service out of the original investment. On the other hand, the process could result in procurement of expensive modifications that may not be essential for the bomber's mission. Thus, it is necessary to weigh each enhancement carefully.

The Administration first requested $59.3 million to enhance the B-1B in its budget proposal for fiscal year 1988.[1] The Congress, however, turned down the request, arguing that the Air Force should concentrate on solving the problems in the B-1B's baseline configuration before beginning enhancements. Furthermore, the Congress forbade the Secretary of Defense to carry out any enhancement of the B-1B unless the enhancement is authorized by law and funds are specifically appropriated for that purpose.[2] The Department of Defense later decided not to submit any requests for B-1B enhancements in its budget for fiscal year 1989.

The debate over B-1B enhancements could be renewed next year, however, when the Congress considers the Administration's budget request for fiscal years 1990 and 1991. This chapter examines 19 enhancements currently being considered by the Air Force. The costs

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1. The Air Force requested $39.8 million in the B-1B account (Program Element 64226F) to begin development of a forward-looking infrared (FLIR) sensor and to begin development of improvements in the B-1B's defensive electronics. The Air Force also requested $19.5 million in an account titled Protective Systems (Program Element 64738F) for work on a countermeasure to more advanced Soviet radars.

2. See Section 244 of the National Defense Authorization Act for Fiscal Years 1988 and 1989.

of the enhancements are based primarily on estimates prepared by the Air Force Aeronautical Systems Division in its proposal for the fiscal year 1990 Air Force budget.

EFFECTS OF DECISIONS ABOUT THE B-2 BOMBER

The merits of the enhancements examined here could be affected by decisions regarding the B-2 "stealth" bomber, which will be designed to minimize the range at which Soviet air defense radars can detect it. Press reports indicate that the United States will begin flight-testing this new bomber sometime this year. The Department of Defense has stated that it plans to build 132 B-2 aircraft at a total cost of $60 billion to $70 billion, with deployment scheduled for the early 1990s.

Because details about the cost, schedule, and capability of the B-2 remain highly classified, it is impossible to analyze fully the impact of deploying this aircraft on the merits of alternative roles for the B-1B and, therefore, on the merits of specific enhancements. Two points seem evident, however. If the United States deploys the B-2 aircraft on schedule, it would be less important that the B-1B be enhanced to increase its ability to penetrate Soviet defenses. But if the B-2 is delayed and one believes it is essential to maintain an effective penetrating bomber, then the urgency of enhancing the B-1B's penetration capability increases. Delays in deploying the B-2 may be caused by the many technical challenges inherent in the B-2 program or by budgetary pressures.

OPTIONS FOR ENHANCING THE B-1B

The Congress could, of course, approve no enhancements to the B-1B bomber or could indefinitely delay consideration. Such action would be consistent with a decision to make no further investments in the B-1B bomber during a period in which the defense budget is growing slowly or decreasing. It might also be consistent with a desire to await progress on the B-2 bomber before making any decisions about enhancing the B-1B. The option to forgo enhancements is not analyzed

separately here, however, since the result is the baseline B-1B bomber discussed in the previous three chapters.

The enhancements being considered by the Air Force can be split into four groups. One group would improve basic support systems for navigation, maintenance, communication, and weapons carriage, enhancing the B-1B's performance as either a penetrating bomber or as a standoff bomber that carries cruise missiles. A second group is related to the B-1B's role as a standoff bomber. The third and fourth groups are related to the performance of the B-1B as a penetrating bomber: the third enhances the B-1B's survivability by improving its ability to penetrate Soviet air defenses; the fourth increases the B-1B's flexibility by improving its sensors and mission-planning capability. These functional groupings serve as the foundation for the options discussed below.

OPTION 1: IMPROVE BASIC SUPPORT SYSTEMS

This option would fund enhancements for navigation, communication, maintenance, and weapons carriage, improving the B-1B's performance as either a penetrating or standoff bomber.

Description of Enhancements

Second Inertial Navigation System. Each B-1B bomber currently carries one inertial navigation system (INS), which tracks the bomber's location by measuring its movements from an initial reference point. The INS is quite reliable, but a failure might make it difficult for the B-1B to find assigned targets.[3] Under normal conditions, a satellite-based navigation system such as the Global Positioning System could substitute for the INS, but such systems might be disrupted during a nuclear war by disturbances in the ionosphere. This program therefore would provide a second INS, for which room has been reserved on the B-1B, that would take over if the first one were to fail.

3. The mean time between failures of the INS is currently estimated to be about 500 flight hours but is expected to rise to more than 1,000 flight hours as the system reaches maturity.

This enhancement program would fund procurement of the INS and installation of the system on all B-1B bombers at an estimated cost of $30 million.

Global Positioning System. The GPS is a satellite system that emits signals that enable military forces to establish their precise location. The B-1B can employ the GPS to update its inertial navigation system. The GPS receiver could not fully substitute for the inertial navigation system, however, since it is dependent on satellite signals that might be disrupted by anomalies in the ionosphere induced by nuclear detonations.

This enhancement program would pay for the procurement and installation of support equipment for the GPS receivers such as power supplies, wiring, and cooling systems at an estimated cost of $60 million. The development and procurement of the receivers themselves would be paid for by the GPS program. This division of funding, in which the aircraft program pays for the components needed to install the new system while the system's program pays for development and procurement, is in accordance with standard Air Force practice.

MILSTAR Communications Satellite System. MILSTAR satellites are being designed to enable command centers to maintain communications with forces during a nuclear war. To accomplish this, the satellites will operate in the super high frequency (SHF) and extremely high frequency (EHF) bands of the radio spectrum. Using these frequencies minimizes disruptions (such as absorption of radio signals and scintillation) that can be caused by a high-altitude nuclear detonation.

This program would fund only the procurement and installation of support equipment for the MILSTAR terminals; the MILSTAR program will pay for the development and procurement of the antennas and terminals. The estimated cost of the enhancement program is $190 million.

Reliability and Maintainability Program. This program would fund solutions to identified shortcomings in parts, support equipment, and software for the B-1B bomber--for example, the redesign of parts such as the B-1B's windshield, which has in some cases delaminated, and

one type of generator that has repeatedly failed. The program would also fund additional support equipment for cruise missiles and radars and would revise some of the software for the Central Integrated Test System. This program would cost about $590 million.

Maintaining Hardness Against a Nuclear Blast. Many electronic components of the B-1B have been "hardened"--that is, designed to resist damage from high-altitude electromagnetic pulse (HEMP), a powerful surge of radio waves caused by a high-altitude nuclear detonation. This program would procure support equipment for testing and maintaining the hardness of B-1B components both aboard the aircraft and at maintenance shops at the B-1B's main operating bases. The estimated cost is $30 million.

Interface for External Weapons. The baseline B-1B has been designed to carry the ALCM-B cruise missile externally. This program would also enable the B-1B to carry externally future conventional or nuclear munitions by providing a new "interface"--that is, the wiring and electronics necessary for current B-1B equipment to communicate with the future munitions. The new interface is based on a set of requirements known as Military Standard #1760.

The specific weapons for which this interface would be used are either classified or yet to be designed. The external interface would not be required for the advanced cruise missile, which will employ the existing interface. Also, this new external interface would probably not be used to support the SRAM II. Although the SRAM II would be compatible, the Air Force will probably only carry it internally since it is designed for use on penetrating missions. Carrying the SRAM II externally on such missions would have the undesirable effects of increasing drag, which would decrease the bomber's range, and of increasing the bomber's radar cross section, which would make it easier for enemy radars to track the bomber.

Although probably not intended to support the advanced cruise missile or SRAM II, the #1760 interface would enable the B-1B to carry classified or future munitions that could conceivably enhance the B-1B's capability as either a penetrating bomber or as a cruise missile carrier. To enhance penetration, the B-1B bomber might carry missiles designed to attack or decoy Soviet fighter-interceptors, to attack Soviet AWACS, to destroy ground-based radars (by detecting

and following radar emissions to their source), to collect reconnaissance data while flying at a high altitude and relay it to the low-altitude bombers.

Such missiles could also enhance the B-1B's future effectiveness as a cruise missile carrier by complicating Soviet efforts to intercept the bombers before they launch their cruise missiles or by relaying reconnaissance data to the cruise missiles assigned to attack mobile targets. Finally, the B-1B could carry advanced munitions externally to improve its capabilities in conventional conflicts. Precision-guided standoff munitions might improve both the B-1B's survivability and the accuracy with which munitions are delivered. This program would cost about $790 million.

Other Enhancements for Support Systems. As other navigation or communication systems are procured, the Air Force will probably plan on modifying the B-1B to accommodate them when appropriate. One other enhancement, the integration of miniature receiver terminals designed for receiving messages over low-frequency radio, is also planned. The special equipment required to accommodate the terminals was installed in 69 B-1Bs during production. The equipment for the remaining B-1Bs will be funded under the B-1B modernization account.

Discussion

The enhancements to basic support systems included in this option would contribute to the B-1B's capability regardless of its mission and therefore are not related to the debate concerning the future role of the B-1B. They would, however, add to costs. Based on the Air Force's preliminary estimates, the programs in this option would cost about $1.2 billion over the next five years and $1.7 billion in total (see Table 1). The main argument against making these enhancements may be budgetary limits, which might be severe in coming years.

But several of these enhancements are not very controversial. Whether the B-1B is operating as a penetrating bomber or as a cruise missile carrier, it is important to maintain or improve its reliability and its hardness to electromagnetic pulse. Since the United States is spending billions of dollars to develop and deploy the GPS and

MILSTAR satellites, it makes sense to enable the B-1B bomber to use the navigation and communication capabilities they provide. Similar rationales might apply to the most expensive program in this option--providing the #1760 interface for external munitions--but that cannot be determined fully in this study since the Air Force's plans for the specific munitions the B-1B would carry are classified.

OPTION 2: IMPROVE THE B-1B's CAPABILITY TO CARRY CRUISE MISSILES

Since the capability to carry cruise missiles internally and externally was incorporated into the design of the B-1B, only two minor programs are required to transfer most B-1Bs from the penetrating mission to the standoff or shoot-and-penetrate missions in which the bomber would carry cruise missiles.

TABLE 1. COST OF OPTIONS FOR ENHANCING THE B-1B
(In millions of current dollars)

	1990	1991	1992	1993	1994	1990-1994	Cost to Complete	Total Cost
Option 1: Improve Basic Support Systems	380	230	280	150	130	1,170	520	1,690
Option 2: Improve the B-1B's Capability to Carry Cruise Missiles	60	20	5	5	a/	90	0	90
Option 3: Improve the B-1B's Survivability as a Penetrating Bomber	380	540	540	440	180	2,080	1,290	3,370
Option 4: Improve the B-1B's Flexibility as a Penetrating Bomber	200	300	380	540	460	1,880	860	2,740
Total	1,020	1,090	1,205	1,135	770	5,220	2,670	7,890

SOURCE: Congressional Budget Office based on Air Force estimates.

a. Less than $1 million.

Description of Enhancements

Cruise Missile Capability. Because the B-1B was produced on a very fast schedule, seven B-1Bs at the beginning of production came off the line without the capability to carry cruise missiles. These B-1Bs need a movable bulkhead between the front and middle weapon bays to accommodate cruise missiles internally and also need modifications to the fuselage to carry cruise missiles externally. These changes, along with the necessary wiring and software, would cost about $60 million.

External Observable Differences. Both the SALT II strategic arms agreement and the draft of the START agreement on strategic arms being negotiated in Geneva require the United States and Soviet Union to distinguish their bombers that carry cruise missiles from those that do not. Consequently, an Air Force Program Management Directive requires B-1B bombers that are carrying cruise missiles, including test aircraft, to display an "external observable difference" (EOD). This enhancement program funds the design, development, and installation of an EOD that would, among other things, minimize aerodynamic disturbances and effects on the aircraft's radar cross section. The estimated cost of this enhancement is $30 million.

Discussion

One of the major issues regarding this option, which does not fund programs to enhance penetration, is how long the B-1B can continue to be an effective penetrator without such enhancements. As discussed in Chapter III, the answer to this question depends on many factors, some of which can be controlled by the United States (for example, tactics such as the number of ballistic missile warheads dedicated to suppressing Soviet air defenses) and some which cannot (for example, whether a Soviet attack is preceded by a crisis or comes out of the blue).

The Air Force, having weighed these factors, has testified that the baseline B-1B without enhancements will be an effective penetrator at least through the mid-1990s. This conclusion would fit with the discussion in Chapter III of the weaknesses of the current Soviet air defenses and the challenges faced in overcoming them. The difficulty

the Air Force is having in completing the B-1B's defensive avionics, however, might alter this conclusion.

Advantages. This option would complete preparations for using the B-1B as a standoff bomber. In the near term, this gives the B-1B the flexibility to operate in any of three roles: penetration, shoot-and-penetrate (launching externally carried cruise missiles before penetrating the Soviet Union), and standoff. Although the Air Force might prefer to continue to use the B-1B as a penetrating bomber as long as its probability of completing its mission is acceptable, under this option it could be easily transferred to the other roles as improved Soviet air defenses decrease that probability to an unacceptable level.

Operating the B-1B in a standoff role has several positive aspects. If the Soviet Union pursued a strategy of forward interception, the B-1B's small frontal radar cross section would make such interceptions more difficult. With the ACM, the B-1B will be able to launch its cruise missiles at greater distances from the Soviet Union, further increasing the difficulty of forward interception. And, on standoff missions, the B-1B will need less support from tanker aircraft, freeing tanker assets for other missions. By combining the capability of a standoff bomber to inundate defenses with cruise missiles and the stealth characteristics of the ACM, the B-1B as a standoff bomber should be an effective strategic weapon well into the next century.

Nor would this option adversely affect the B-1B's capability in many conventional conflicts. First, as discussed in Chapter III, because of the increasing sophistication of air defenses in many regions of the world and the lower acceptable level of attrition on conventional missions, standoff weapons are gaining favor over bombs for attacking fixed targets in conventional conflicts. This option is consistent with that trend. In addition, if a choice were made to use the B-1B as a penetrating conventional bomber--perhaps against undefended targets--the penetrating capability of the baseline B-1B maintained in this option would serve well.

This option also is consistent with the Administration's original two-bomber plan supporting procurement of the B-2 stealth bomber. If the B-1B will be an effective penetrator through the mid-1990s, and if the B-2 is deployed in the early to mid-1990s as the nation's primary penetrating bomber, then it might be unnecessary to invest in addi-

tional enhancements for the B-1B as a penetrator and might be appropriate to prepare the B-1B for transition to a shoot-and-penetrate role and eventually a standoff role.

Finally, the enhancements under this option are relatively inexpensive. Based on preliminary estimates by the Air Force, the enhancement programs in this option would cost a total of about $90 million, all spent over the next five years (see Table 1). A decision to pursue these enhancements, however, might be logically coupled with a decision to enhance basic support systems as discussed in Option 1. Both options together would cost about $1.8 billion.

Disadvantages. One problem with this option is that the Air Force is having difficulty completing the baseline B-1B's defensive avionics, so the baseline B-1B might not be an effective penetrator for as long as the Air Force has anticipated.

More important, if the B-2 is not deployed, or if its deployment is delayed significantly because of budgetary limits or technical problems with the new aircraft, the United States could find itself without an effective penetrating bomber. From the viewpoint of advocates of penetrating bombers, that would be a major mistake since the United States would forfeit the advantages of these bombers.

Even if the B-2 is deployed, the United States might want to maintain more than 132 penetrating bombers (the planned number of B-2s) both for traditional missions against fixed sites and for missions against the growing number of Soviet mobile facilities. Because of the B-2's high costs, maintaining the B-1B as a penetrating bomber for an extended period might be the only affordable way to deploy a larger fleet of penetrating bombers. Doing so, however, might require enhancements beyond those included in this option.

OPTION 3: IMPROVE THE B-1B'S SURVIVABILITY AS A PENETRATING BOMBER

The ability of the baseline B-1B to penetrate Soviet defenses will decline as Soviet air defenses improve. This option would endeavor to prevent that decline, seeking to maintain the B-1B as an effective

penetrator beyond the year 2000. In particular, this option provides for integrating an improved short-range attack missile and for improving defensive and offensive avionics. With these enhancements, the B-1B should be better able to foil advanced Soviet look-down/shoot-down air defense technology and, when that fails, to destroy defensive threats.

Description of Enhancements

Integration of SRAM II. The SRAM II is expected to have better reliability, accuracy, range, and targeting flexibility than the current SRAM-A, helping the B-1B to penetrate Soviet air defenses by improving its ability to destroy air defense installations encountered en route to a target. To carry the SRAM II in its weapon bays, however, the B-1B needs a new weapon interface. This enhancement program would provide that interface. It would be based, like the interface for external munitions discussed in Option 1, on Military Standard #1760. To save money, the Air Force does not intend to conform to all requirements in that standard. The interface, for example, would use standard wires rather than fiber optics for carrying signals.

This program would procure and install the interface. It would not pay either for development or for testing, which are funded in other programs. This enhancement would cost about $610 million.

Monopulse Countermeasure. Several of the most sophisticated Soviet air defense systems use a monopulse tracking radar. A monopulse radar uses a single pulse to establish both the azimuth and elevation of a target. This enhancement program would strive to develop and deploy the best possible countermeasure to these advanced Soviet systems. The estimated cost of this enhancement is about $1.4 billion.

Forward Warning System. As noted in Chapter II, the baseline B-1B's defensive avionics will include a tail warning function--a radar system that searches for air-to-air missiles approaching the B-1B bomber from the rear. The forward warning system would do the same for missiles approaching the B-1B from the front. This capability would be particularly useful for detecting "all-aspect" infrared-guided missiles that the Soviet Union might deploy in the future. Development,

procurement, and installation of this system would cost about $660 million.

Improved #1122 Countermeasure. This program would improve the classified #1122 electronic countermeasure to Soviet air-to-air missiles. This program would cost about $60 million.

Research and Development Assets. Laboratories currently use parts from the spares inventory to conduct developmental testing on the B-1B's defensive avionics. This enhancement program would purchase additional assets specifically for the development program. The estimated cost of this enhancement is $170 million.

Operation of Anechoic Chamber. The Air Force is building a large anechoic chamber (the walls absorb electromagnetic waves, eliminating echoes) for testing the avionics of many aircraft, including the B-1B. Using this chamber, the Air Force can test the response of the B-1B's defensive avionics to Soviet electronic countermeasures, and the integration of the B-1B's offensive and defensive avionics. An important advantage of this chamber is that the Soviet intelligence network will not be able to pick up the emissions and exploit them to design countermeasures.

This program would rent a specific amount of time in the chamber for testing the B-1B over a five-year period (the rental fee pays for the cost of maintaining and operating the chamber; construction was financed under a separate account). Using the chamber would be particularly helpful in developing and testing revised architectures for the B-1B's defensive avionics system. The Air Force estimates the cost of renting this chamber for testing the B-1B to be about $70 million for 1990 through 1994.

General Avionics Enhancements. This program would fund ongoing improvements in the offensive and defensive avionics such as increased computer memory, computational speed, and data storage. It would also seek to improve the "man-machine interface," modifying the way that terrain-following profiles, radar-generated maps, and defensive threats are displayed in the cockpit. The estimated cost of this enhancement program is $360 million.

Other Enhancements. The Air Force, as noted in Chapter II, is currently studying alternatives for changing the basic architecture of the B-1B's ALQ-161 defensive avionics system. When that study is completed in October 1988, the Air Force will probably propose a specific program for designing and implementing the revised architecture. The Air Force might request funds for that program under the B-1B baseline program or under a separate enhancement program. As more is learned about specific Soviet air defense systems, the Air Force will most likely consider other programs. For example, the service might seek to modify the B-1B's infrared signature, improve the bomber's chaff and flares, decrease reliance on active radar for terrain-following, or perhaps employ new types of towed, ejected, or free-flying decoys.

Discussion

This option is a package of enhancements designed to maintain or improve the capability of the B-1B to penetrate Soviet air defenses despite improvements in those defenses.

Advantages. The enhancements in this option would increase the probability that the B-1B would be an effective penetrating bomber beyond the year 2000. For proponents of penetrating bombers, this ensures that the United States will have an effective penetrator even if problems arise in the design and production of the B-2.

Proponents on all sides of the debate over penetrating bombers and standoff bombers might find merit in the fact that this option would reduce the pressure for building the new B-2 immediately, possibly enabling the program to proceed at a more measured pace that lowers the risks inherent in concurrent development and production. In addition, before making a commitment to produce the expensive B-2 bomber, the Congress could use the additional time to ascertain that the B-2 offers advantages that have not already been largely realized through the development of cruise missiles.

Disadvantages. Expense is a major drawback to this approach. This option is expected to cost about $3.4 billion, with $2.1 billion to be spent over the next five years compared with about $90 million for Option 2. As with Option 2, Option 3 could be pursued in tandem with

the enhancements to basic support systems under Option 1. The combined cost of Options 1 and 3 would total about $5.1 billion.

The costs of this option are only part of the costs of maintaining the B-1B as a penetrator beyond the turn of the century. If that is the goal, it makes sense to deploy on the B-1B the new SRAM II short-range missile, currently scheduled for initial procurement in fiscal year 1991 and deployment by April 1993. Procuring the SRAM II for the B-1B might cost an additional $600 million to $700 million.[4] On the other hand, if the Air Force maintained the B-1B under this option only as a penetrator, the Air Force might choose to delay the advanced cruise missile, saving money.

Nor is it clear that these added funds provide additional capabilities that are critical to maintaining the B-1B as an effective penetrator beyond the year 2000. As noted in Chapter III, the United States can influence the B-1B's effectiveness as a penetrator through choice of tactics and missions. In addition, weaknesses in future Soviet air defenses, such as the potential vulnerability of Soviet AWACS to attacks by fighters, might prevent those defenses from becoming a significant threat to the B-1B's ability to penetrate.

In the opinion of cruise missile proponents, this option spends money without achieving any significant capability not currently possessed by standoff bombers equipped with cruise missiles. Proponents argue that cruise missiles are good penetrators currently and offer flexibility for enhancements that could match improvements in the Soviet air defenses.

OPTION 4. IMPROVE THE B-1B'S FLEXIBILITY AS A PENETRATING BOMBER

Like Option 3, this option is designed to improve the B-1B as a penetrating bomber. Rather than improve its survivability, however, this option would improve its flexibility, better enabling it to attack dif-

4. The Air Force estimates that procuring the SRAM II will cost about $0.8 million per missile. The additional cost of procuring SRAM IIs under this option is based on procuring eight SRAM IIs for each of the 99 B-1B bombers.

ferent types of targets--particularly mobile targets--under varied conditions.

Description of Enhancements

Improved Synthetic Aperture Radar. The eye of the offensive avionics system is a synthetic aperture radar in the nose of the B-1B bomber. One important function of this radar is to make high-resolution maps of the ground. This enhancement program would upgrade the resolution of those maps and provide target-recognition software to help the B-1B crew detect mobile targets such as mobile Soviet ICBMs. The estimated cost of developing and deploying this sensor is $640 million.

High-Resolution Infrared Sensor for Targeting. A forward-looking infrared (FLIR) sensor records emissions in the infrared sector of the electromagnetic spectrum, much as a television camera records emissions in the sector of visible light. Electromagnetic emissions in the infrared sector are caused by heat, and a FLIR sensor maps features (such as hills, roads, and rivers) by distinguishing between their respective temperatures.

The goal of this enhancement program is to produce a FLIR sensor that has high enough resolution not only to see major features of the terrain but to distinguish between types of trucks, improving the ability of the B-1B crew to find and identify mobile targets. This program would also provide a laser range-finder and would be designed to facilitate interaction with any target recognition system (such a system would alert the crew when the sensor detects a potential target) that might be developed in the future.

The high-resolution FLIR sensor and laser range-finder might also provide a substitute for the automatic terrain-following radar system the B-1B currently employs. Whereas the ATF system emits radar energy that could disclose the B-1B's location to future Soviet ground-based sensors, the infrared sensor does not.

The Air Force estimates that the cost of developing and procuring this enhancement would be $1 billion.

On-Board Mission Planning System. This system would have two basic functions: it would create a "paperless cockpit" by providing electronic displays of checklists, maps, and combat mission folders; and it would create an electronic workstation for calculating potential changes in a mission. For example, if a B-1B were to receive information about a potential mobile target or concentration of air defenses during a mission, this system would help the crew to calculate the possible consequences of various responses. The Air Force estimates that the cost of this option would be about $590 million.

Low-Resolution Infrared Sensor for Situational Awareness. During a penetrating nuclear mission, the B-1B crew would have no continuous indication--or "situational awareness"--of the surrounding terrain. Visual contact with the ground is largely limited by a special curtain drawn across the cockpit window to protect the crew from the flash of light from a nuclear detonation. Although the offensive radar system can create images of the surrounding terrain, its primary task is to supply data to the automatic terrain-following system to keep the bomber close to the ground.

A forward-looking infrared (FLIR) sensor for situational awareness would provide that continuous indication of surrounding terrain. The resolution of the FLIR is not high enough to aid targeting, but it would keep the crew aware of their surroundings, avoiding surprises while flying at low altitudes to penetrate enemy territory. The system also would facilitate nighttime landings at unlit airfields. The Air Force estimates that this sensor would cost $370 million. To use either this sensor or the targeting FLIR sensor discussed above, the Air Force also would need a display system, which would cost an additional $130 million, for a total of $500 million.

Discussion

The sensors and on-board mission planning system are intended to improve the flexibility of the B-1B as a penetrating bomber, potentially improving its performance in finding and attacking mobile targets, conducting a damage assessment/strike mission, or performing conventional missions.

Advantages. The enhancements in this option would better enable the bomber to conduct missions against mobile targets. The improved synthetic aperture radar (SAR) and the targeting FLIR sensor would provide more data than the B-1B's current SAR on the location of systems such as mobile Soviet ICBMs. The on-board mission planning system would begin to provide the autonomous planning capability necessary to respond to a flow of data regarding the potential location of a mobile target. Such data might come from space-based sensors, high-flying intelligence aircraft, or expendable drones.

The enhanced SAR and targeting FLIR sensor might also improve the B-1B's ability to conduct a damage assessment/strike mission in which the bomber crew flies the bomber over a target, determines whether a previous attack has destroyed it, then decides whether to attack it again.

This option would also increase the capability of the B-1B bomber in a variety of nuclear and conventional missions by improving its low-altitude navigation with the low-resolution FLIR.

Disadvantages. The enhancements in this option are expensive. The price tag of $2.7 billion, when converted to constant 1981 dollars, is 7 percent of the $20.5 billion invested in developing and procuring the baseline B-1B. Viewed in terms of opportunities forgone, the funds needed to finance Option 3 would buy a substantial share of the advanced cruise missiles required to equip a fleet of standoff B-1B bombers.

Given the goal of maximizing the B-1B's performance as a penetrating bomber, it would be logical to combine this option with Option 1 (to improve basic support systems) and Option 3 (to improve the survivability of the B-1B as a penetrating bomber). The cost of the combined options would be $7.8 billion--about 21 percent of the amount invested in developing and procuring the baseline B-1B.

The enhancements in this option are basically unrelated to the B-1B's ability to accomplish its current primary mission of penetrating Soviet air defenses and attacking fixed targets. Consequently, unless the B-1B is assigned the mission of finding and attacking mobile targets, these enhancements might contribute little to the bomber's performance.

In addition, it is not clear that this option would provide any significant capability to find and destroy mobile Soviet targets. To establish that the sensors funded under this option would provide such a capability, more detailed information is needed regarding, among other factors, the capability of sensors and their susceptibility to decoys and deception (see Chapter III). The development of the plans for the sensors and their use on the B-1B appears to be too rudimentary to provide a foundation for evaluating these crucial questions.

Even if the sensors provided a significant capability to find mobile missiles, such a task might not be a wise use of the B-1B bomber because it might divert the bomber from other, more important, missions or increase the bomber's vulnerability to Soviet air defenses (the B-1B might have to fly more slowly and at higher altitudes to use its sensors effectively).

Before undertaking an expensive plan to enable the B-1B to search for mobile targets, comparisons should be made between using the B-1B for that mission and using ICBMs, SLBMs, cruise missiles, and the B-2. Because the necessary sensor capability has not been demonstrated yet, it is not possible to make such comparisons. Moreover, from a policy standpoint it is not clear that it is essential, or even desirable, that the United States aggressively pursue the capability to destroy mobile Soviet targets.

Other Enhancements. As the operational concept for attacking mobile targets develops and new technologies mature, the Air Force will probably plan additional enhancements for expanding the B-1B's flexibility as a penetrating bomber. Those enhancements might involve measures to increase its range, such as carrying external fuel tanks, or additional methods to improve the B-1B's search capability. Millimeter-wave radar, for example, is being explored as a complement to infrared sensors for finding mobile targets.

Finally, the purposes of the low-resolution FLIR sensor--improving the crew's awareness of the terrain over which the bomber is flying and enhancing nighttime landings--do not appear to be essential for conducting either penetrating or standoff missions. The cost must therefore be weighed against a marginal contribution to the B-1B's primary missions.

CONCLUSION

Although the Air Force is actively considering the B-1B enhancements discussed in this paper, they have not been formally presented to the Congress. The Department of Defense may choose to present some or all of them, however, as part of its fiscal year 1990 budget.

Nevertheless, it might be appropriate for the Congress to begin considering these options, since they are related to difficult questions such as the current and future capability of the B-1B to penetrate Soviet air defenses and the relative merits of penetration versus standoff tactics. Moreover, decisions about enhancements for the B-1B bomber may affect other decisions that will be made this year regarding the pace of development and procurement for the advanced cruise missile, the SRAM II short-range missile, and the B-2 stealth bomber. Finally, some of the enhancements are directly related to the search for a method to attack the growing number of mobile Soviet targets.

APPENDIXES

APPENDIX A

METHODOLOGY FOR CALCULATING THE PAYLOAD CAPACITY AND RANGE OF THE B-1B ON TERRAIN-FOLLOWING MISSIONS

The B-1B was designed to carry a large payload (fuel and munitions) while flying at low altitudes, following the terrain to escape detection by Soviet radars. Currently, however, the bomber cannot, during terrain-following flight, carry as large a payload as anticipated. Therefore, for any given load of munitions, it can carry less fuel than planned, reducing its operational range.

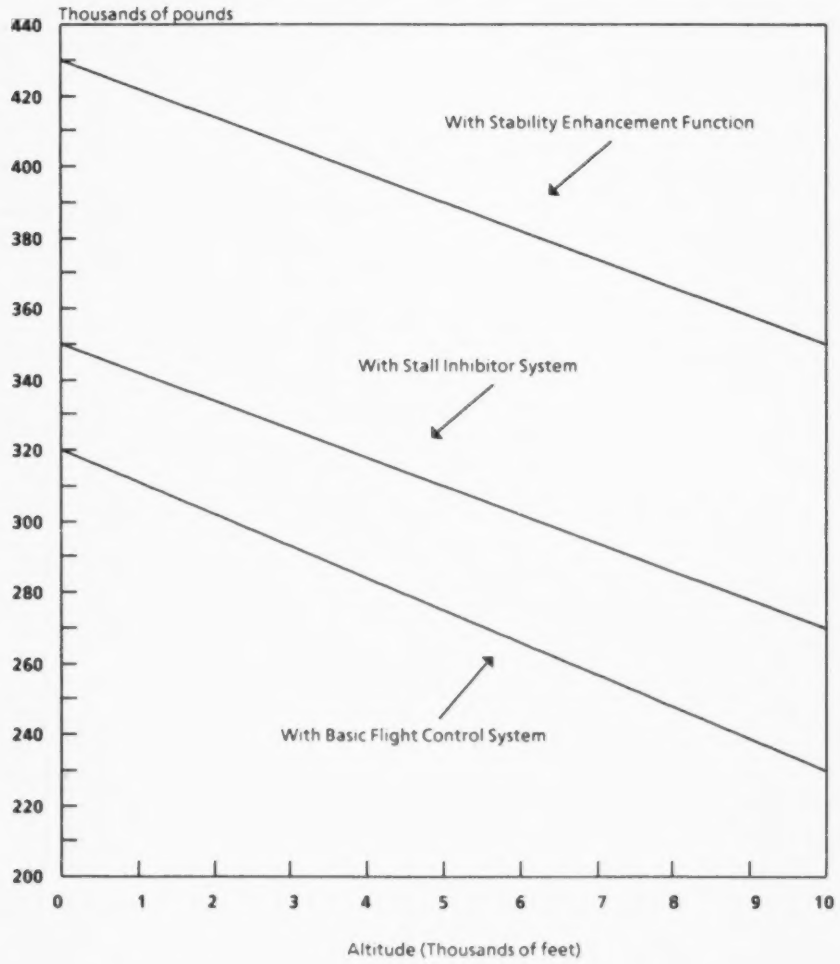
PAYLOAD CAPACITY

As depicted in Figure A-1, the Air Force estimates that the B-1B equipped with the basic flight control system (FCS) can fly safely--that is, can maintain the maneuvering capability desired by the Air Force of 2.4 g's (gravitational equivalents) for 10 seconds--with a maximum gross weight of 312,000 pounds at 1,000 feet (equivalent to flying 200 feet above land that has an altitude of 800 feet).

When the B-1B's flight control system is modified with the Stall Inhibitor System (SIS) or Stability Enhancement Function (SEF), the bomber will be able to fly safely at a higher angle of attack, increasing the amount of weight it can carry while maintaining the desired maneuvering capability. The Air Force estimates that when the B-1B is flying at an altitude of 1,000 feet, it will have a maximum gross weight of 342,000 pounds with SIS and about 422,000 pounds with SEF (see Figure A-1). The estimate for SIS is based on substantial testing, but the estimate for SEF is based on preliminary engineering evaluations and could change substantially.

The payload capacity of the B-1B at low altitudes is equal to the maximum gross weights noted above minus the weight of the bomber itself. Thus, as presented in Table A-1, the payload capacity of the B-1B equipped with the basic flight control system is about 125,000

Figure A-1.
Gross Weight Limits of the B-1B During Terrain-following Flight



Assumptions: Bomber is flying with a wing sweep of 67 5 degrees at velocity of Mach 85, maintaining the ability to pull up at an acceleration rate of 2 4 g's (gravitational equivalents) for 10 seconds

SOURCE: U S Air Force

pounds. The payload of the B-1B equipped with SIS increases to about 155,000 pounds. With SEF, the payload is about 234,000 pounds.

RANGE

The B-1B's range during low-altitude, terrain-following flight depends on the amount of fuel it can carry, which in turn depends both on the bomber's payload and on the amount of the payload dedicated to munitions. For example, the range could be calculated based on a full load of 24 SRAM-As which, with support equipment, would weigh over

TABLE A-1. CALCULATION OF THE B-1B's PAYLOAD CAPACITY
(In pounds)

	B-1B Equipped With:		
	Basic Flight Control System	Stall Inhibitor System	Stability Enhancement Function
Maximum Gross Weight for Flying at Low Altitudes[a]	312,000	342,000	422,000
Weight of the Basic B-1B			
B-1B empty	182,360	182,360	182,360
Crew	900	900	900
Miscellaneous equipment and supplies[b]	3,630	3,630	3,630
Fuel tank in bomb bay	n.a.	n.a.	1,130
Payload Capacity	125,110	155,110	233,980

SOURCE: Congressional Budget Office using data supplied by the U.S. Air Force.

NOTE: n.a. = not applicable.

a. Assumes that the bomber is flying at an altitude of 1,000 feet above sea level. This would be the case, for example, if the bomber were flying 200 feet above land having an altitude of 800 feet (see Figure A-1).

b. Includes parachutes, food, water, engine fluids, inaccessible fuel, flares, and chaff.

59,000 pounds. The Air Force, however, would probably not send the B-1B on a strategic mission with that large a load. This analysis assumes instead that the B-1B is carrying a lighter load of eight SRAM-As and eight B61 bombs, leaving one bomb bay empty for carrying fuel. With this assumption, and some fuel set aside for recovering to a friendly base following the low-altitude flight, the B-1B has about 79,000 pounds of fuel for its low-altitude flight when equipped with the basic flight control system, 109,000 when equipped with SIS, and--if the preliminary Air Force estimates prove accurate--188,000 pounds for the B-1B equipped with SEF (see Table A-2).

The B-1B's range during terrain-following flight is affected by the bomber's velocity as well as by the amount of fuel it can carry. This

TABLE A-2. DISTRIBUTION OF THE B-1B'S PAYLOAD WHEN THE BOMBER CARRIES EIGHT SRAM-As AND EIGHT B61 BOMBS (In pounds)

	B-1B Equipped With:		
	Basic Flight Control System	Stall Inhibitor System	Stability Enhancement Function
Payload Capacity	125,110	155,110	233,980
Munitions			
Eight SRAM-As	17,680	17,680	17,680
Eight B61 Bombs	6,010	6,010	6,010
Support equipment	4,130	4,130	4,130
Fuel Needed for Recovery[a]	18,300	18,300	18,300
Fuel Available for Low-Altitude Flight	78,990	108,990	187,860

SOURCE: Congressional Budget Office analysis of data supplied by the U.S. Air Force.

a. The B-1B specifications for recovery require that the bomber, following its low-altitude approach to and escape from the target, be able to fly 575 miles (500 nautical miles) at an altitude and velocity that maximize fuel-efficiency and to loiter for 30 minutes while preparing to land.

study assumes that the bomber's low-altitude flight has two parts: a longer approach to the target (two-thirds of the total low-altitude flight) at the higher speed of about 650 miles per hour; and a shorter escape from the target at about 420 miles per hour.

The B-1B's range, given these assumptions, depends on its fuel efficiency. Based on Air Force estimates for the fuel efficiency of the bomber at various gross weights, the B-1B equipped with the basic FCS could fly a terrain-following mission of 1,480 miles. No allowance is made in this calculation, however, for engines operating at less than the specified efficiency, or for extra fuel being expended in flying over varied terrain or in fighting head winds. To plan for such contingencies, this analysis assumes that a 10 percent cushion is necessary. Thus, the B-1B with the basic FCS can undertake a terrain-following mission of about 1,330 miles. The corresponding range for the B-1B with SIS is about 1,820 miles and with SEF is about 3,000 miles.

APPENDIX B

WIDE-AREA TRACKING SYSTEMS FOR SOVIET AIR DEFENSES

The two major challenges in establishing an effective air defense system are to detect and track penetrating bombers and cruise missiles, and to deliver munitions to the appropriate location to destroy them. This appendix discusses techniques the Soviets currently employ or might employ in the future to meet the first challenge. As evident from the discussion below, there are drawbacks to every approach. During a nuclear war in the near future or years from now, the Soviet Union may have a difficult time tracking penetrating bombers and cruise missiles.

GROUND-BASED RADARS

The Soviet Union's air defenses rely primarily on thousands of fixed, line-of-sight radars to find and track enemy bombers. Such radars have several advantages: they can be easily supplied with electrical power, they are inexpensive to maintain, and they can detect high-altitude aircraft at long distances. In addition, the data from many ground-based radars can be communicated to a common processing facility, enabling the radars to operate collectively like a single radar with much greater range. Such a radar network facilitates the coordination of fighters and provides more time for guiding them to intercept a penetrating bomber or cruise missile.

Fixed ground-based radars also have important shortcomings. Because they are easy to locate and very "soft" (not designed to withstand the shock waves generated by a nuclear detonation), they can be targeted and destroyed by U.S. nuclear weapons. Once their location is established, a flight path can be designed to fly around them. Moreover, the range of a single ground-based radar against low-flying aircraft or cruise missiles is limited by the earth's curvature to about

20 to 50 miles.[1] Connecting radars into a network does not solve this problem unless the radars are close enough for their coverage to overlap. There are many gaps between the coverage of Soviet ground-based radars through which bombers might fly undetected.

The Soviet Union could improve its ground-based radar network by deploying mobile radars, which are harder to locate and therefore harder to attack. Because a penetrating bomber or cruise missile might not know where the radars are located (depending on how recently they have been moved), it might not be possible to plan a flight path to avoid them. Mobile radars, however, also have shortcomings. Like fixed line-of-sight radars, they have limited range against low-altitude penetrators. In addition, there are so many potential gaps in the Soviet ground-based network that plugging all of them with mobile radars would require a massive commitment of resources and personnel.

AIRBORNE WARNING AND CONTROL SYSTEM

The primary way in which the Soviet Union is seeking to remedy the shortcomings of its ground-based radars is to deploy large radars on aircraft. These aircraft, which are known as Airborne Warning and Control Systems (AWACS), monitor enemy penetrators and coordinate air defenses over a large area. The range of an AWACS is much greater than that of ground-based radars--over 200 miles to the horizon and over 400 miles to another aircraft at a high altitude. When airborne, the AWACS cannot be targeted in advance since its precise location is unknown.

The first Soviet AWACS, the Moss, was relatively ineffective in tracking low-flying bombers and cruise missiles. The more recent Soviet AWACS, the Mainstay, is considered to be much more capable. The Mainstays might patrol near the Soviet borders to track approaching U.S. bombers, providing the greatest possible time to

1. A line-of-sight radar standing 50 feet above the ground theoretically can detect at about 30 miles a bomber flying at 300 feet above the ground. At greater distances, the bomber is hidden by the earth's curvature. The actual detection range might be less than the theoretical range because of the disruption or blocking of radar pulses by terrain features such as hills. The actual detection range might be greater than the theoretical range if the radar is located on a hill.

guide fighters to intercept them. Such patrols would force U.S. bombers to start flying at low altitudes earlier in their flight, perhaps at distances of 300 to 400 miles from Soviet territory. The bombers would have to do this to minimize the distance at which the AWACS can detect them, possibly decreasing the bombers' range (low-altitude flight is less fuel-efficient than high-altitude flight). The Soviet Union has so far deployed only a few Mainstay AWACS, but it is expected to continue expanding the fleet.

The Soviet Mainstay AWACS, however, has several shortcomings. When on the ground, it is vulnerable to a surprise attack. If the Soviet Union tried to counter this vulnerability by keeping its AWACS on patrol continuously during a crisis, their capability would be degraded by the necessity of more frequent repairs. In addition, during a large-scale nuclear war, the United States would probably attack many Soviet airfields with ballistic missiles, complicating the AWAC's efforts to land and refuel. Such refueling might be necessary, since U.S. bombers might not arrive near the Soviet Union until 8 to 10 hours after a strike by U.S. ballistic missiles.[2]

Moreover, if the AWACS were a significant threat, the United States could modify the Strategic Integrated Operational Plan (SIOP, the U.S. blueprint for conducting a nuclear strike) to include the use of fighter aircraft to destroy the AWACS. The AWACS are vulnerable to an attack by fighters because they are large and slow, fly at high altitudes, and emit strong radar signals. The AWACS also might be susceptible to electronic countermeasures designed either to jam or to confuse them.

OTHER RADAR SYSTEMS

The Soviet Union could employ many other technologies to attempt to improve the tracking capability of its air defense system. Possible technologies include over-the-horizon radars, space-based sensors, networks of radio-signal receivers, and radars carried on balloons.

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2. Refueling at airfields could be avoided by using tanker aircraft. The Soviet Union could, for example, refuel the Mainstay using the new Soviet tanker, the Midas. It is not clear, however, whether this would be a primary mission for the Soviet Union's small fleet of tanker aircraft.

Over-the-Horizon Radars

Over-the-horizon (OTH) radars use a large antenna array to direct a signal at the ionosphere (an electrically charged band in the upper atmosphere). The ionosphere refracts the signal, sending it back to earth to a location far beyond the horizon. The signal is reflected back to the ionosphere by an object such as an aircraft and refracted back to a receiving antenna array on the earth.[3] The main advantage of this technology is that a single OTH radar can scan a very large area, with ranges of about 500 to 1,800 miles.

The Soviet Union faces several problems in employing this technology to remedy the deficiencies of its ground-based radar coverage. One problem is that the ionosphere is very inconsistent in the polar regions, complicating the use of OTH technology. This is a major problem since most routes for U.S. bombers would pass through the polar region. Another problem is that, during a nuclear war, the United States could alter the properties of the ionosphere--and therefore disrupt OTH radar transmissions--by detonating a ballistic missile warhead outside the ionosphere. The United States could also easily destroy the antenna arrays with ballistic missiles before the OTH radar could help track bombers. Finally, OTH radars are susceptible to electronic countermeasures.

Although the Soviet Union might employ OTH radars for tactical warning, this technology does not appear promising for significantly improving Soviet tracking capability during a nuclear war. Furthermore, although some work is being done on over-the-horizon radars that would use troposcatter or meteor-burst propagation, in place of ionospheric propagation, both techniques have limitations that make them unlikely candidates for providing a full solution to the problem of tracking low-flying bombers and cruise missiles during a nuclear conflict.[4]

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3. The radar uses the Doppler effect in which the frequency of a signal reflected off an object moving toward the radar is increased. This effect allows the radar's computers to sort out the signal bouncing off an aircraft from signals bouncing off the ocean.

4. Troposcatter propagation employs irregularities in the lower troposphere (an altitude of 30,000 to 50,000 feet) to scatter a radar beam back to earth. Meteor-burst propagation uses the highly ionized column of air left by a meteor passing through the atmosphere to reflect a radar beam over the horizon.

Space-based Sensors and Radars

Another way to detect low-flying bombers would be to deploy some type of infrared (heat-detecting) sensor or radar on satellites. An infrared sensor, for example, could take a series of images and use a computer to compare the images, searching for a moving heat source that might represent the exhaust from a bomber's jet engines. Potential advantages of such sensors include low maintenance and wide coverage. Disadvantages might include the initial high cost of building and deploying the satellite; the vulnerability of the satellite to attack by an antisatellite weapon, radiation from an exoatmospheric nuclear detonation, and illumination by ground-based lasers (the lasers might damage the satellite's sensors); and the vulnerability of the communications link with the earth to disturbances in the ionosphere caused by nuclear detonations. The effectiveness of an infrared sensor might also be countered by techniques such as dispersing jet engine exhaust so that the infrared signature is weaker. Space-based radars face similar challenges.

Space-based infrared sensors and radars might eventually contribute to the mission of tracking bombers during a nuclear war. But, at least during the 1990s, they are not likely to represent a major threat to U.S. bombers.

Radio Receivers

Another technology that could be used for wide-area surveillance is the radio-signal receiver, which would detect an aircraft's radio (including radar) emissions. For example, the Soviet Union could use a network of ground-based receivers to track a B-1B by detecting emissions from its terrain-following radar, or an ALCM-B by detecting emissions from its terrain-mapping radar. Unlike a conventional ground-based radar, a receiver does not emit a signal. It might therefore succeed in concealing its location, making it difficult for U.S. penetrators to avoid or destroy it.

For these receivers to contribute to tracking, many thousands would have to be deployed and linked together. If the Soviet Union pursues such a network, U.S. bombers might be able to counter it by using laser rather than radar altimeters and by replacing terrain-

following radars with infrared terrain-avoidance systems (passive infrared sensors are used to view the terrain, helping the pilot to fly low without hitting hills). Alternatively, bombers could navigate by correlating their precise position (established by using inertial or satellite guidance systems) with data on altitude drawn from computerized data bases stored on the bombers.

Balloon-carried Radars

Another innovative technique for wide-area tracking is to deploy radars at high altitudes with balloons, which can carry a heavy load for extended periods. The U.S. Navy, for example, awarded a contract in 1987 for a prototype dirigible that would carry a large internal radar 5,000 to 10,000 feet above a Navy fleet, helping to spot enemy aircraft and low-flying missiles.

More study is required to determine the value of this technology. The advantages it gains in range or mobility might be balanced by disadvantages related to cost, flexibility, or survivability.

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